Advanced Spotter Training 2021

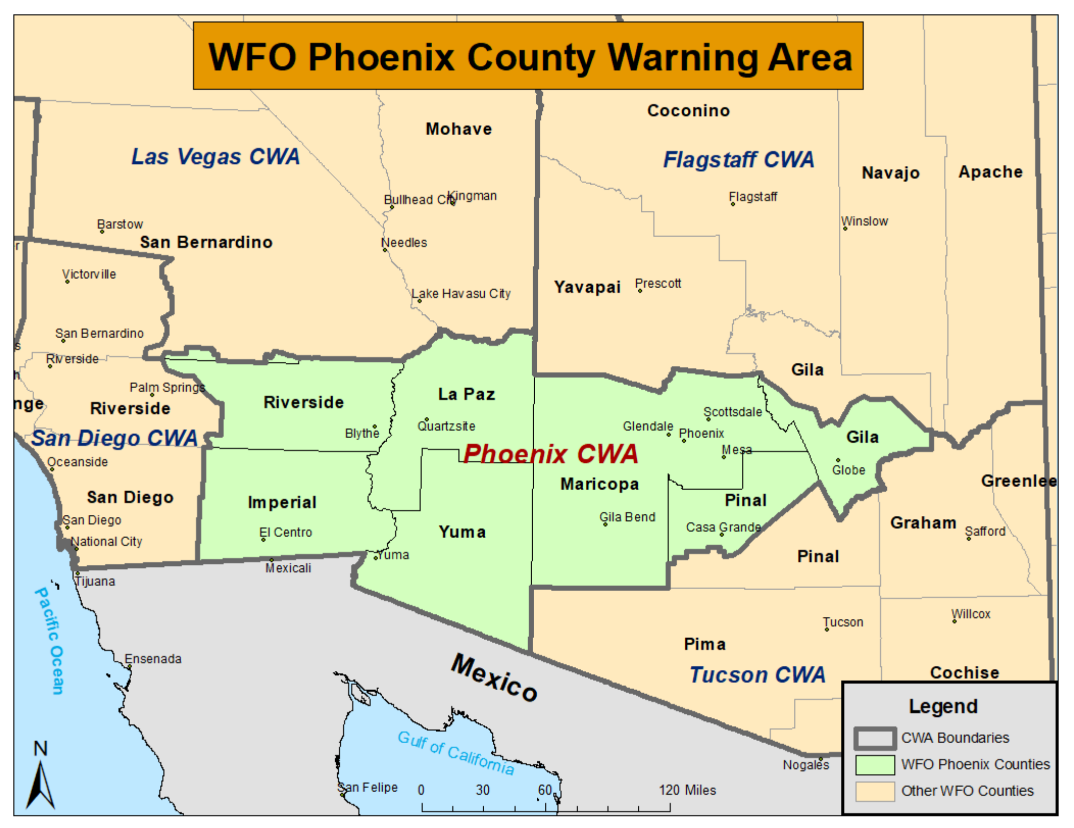
Austin Jamison
National Weather Service – Phoenix, AZ

Photo: Mark Rebilas

About Our Office

NWS Phoenix

- 13 Forecasters, 4 electronic technicians/IT support, 1 administrative support assistant, 1 hydrologist, 1 observations program leader, 1 science & operations officer, 1 warning coordination meteorologist, and 1 meteorologist in charge.
- Open 24/7/365 to provide essential forecasts and warnings for the public, emergency management, aviation, land management, road management, water management…



Program Outline

Part I

- Organized Storm Ingredients
- Storm Classification
- Tornadoes & Land Spouts
- The Monsoon

Part II

- Mesoanalysis Tools
- Radar Analysis
- Case Studies

Five Fundamental Rules

- Warm Air Rises
- Cool air sinks
- Stuff runs downhill
- Stuff gets blown downwind
- What goes up, must come down

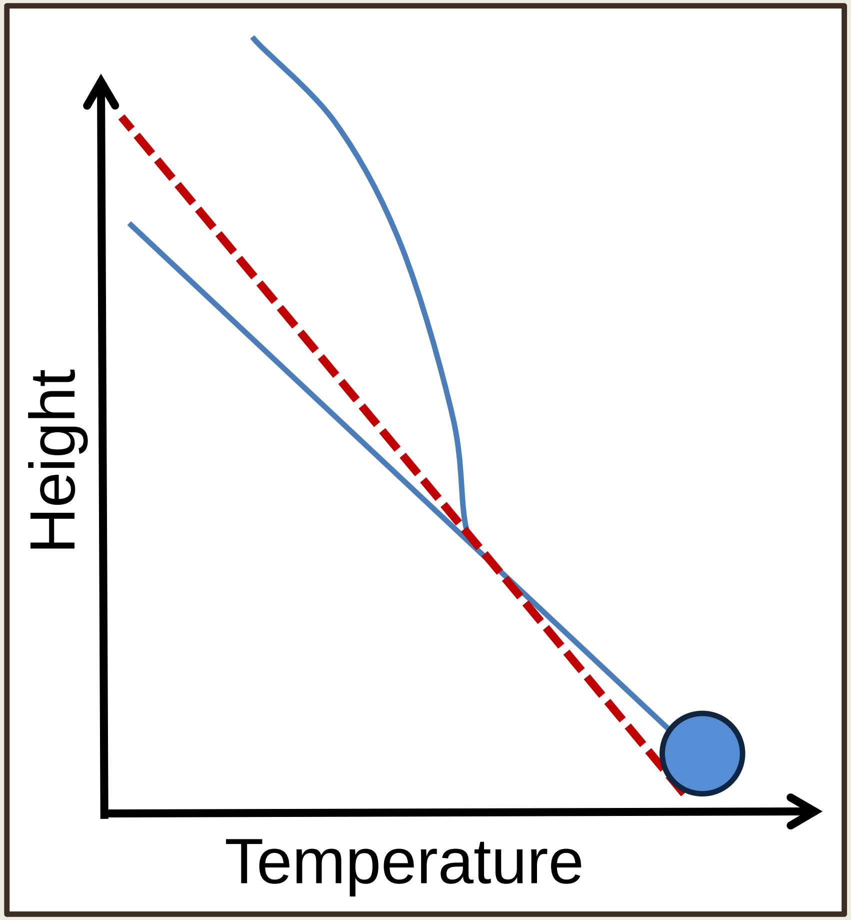
Organized Storm Ingredients

- Moisture
- Instability
- Lift
- Wind Shear

Stan Celestian

Moisture

- Moisture is necessary for cloud formation and precipitation
- Moisture increases instability (aka CAPE). *Why is this?*
- **LATENT HEAT RELEASE –** this thermodynamic process occurs when water vapor in saturated air parcels **condenses** to form cloud droplets; the parcel of air is **warmed** relative to its surroundings



Instability

- Air parcels that are warmer than the environment are less dense and will rise - **UNSTABLE**

- Air parcels that are cooler than the environment are more dense and will sink - **STABLE**

- The larger the temperature difference between the parcel and the environment, the greater the instability.

Jeremy Perez

How do we measure instability?

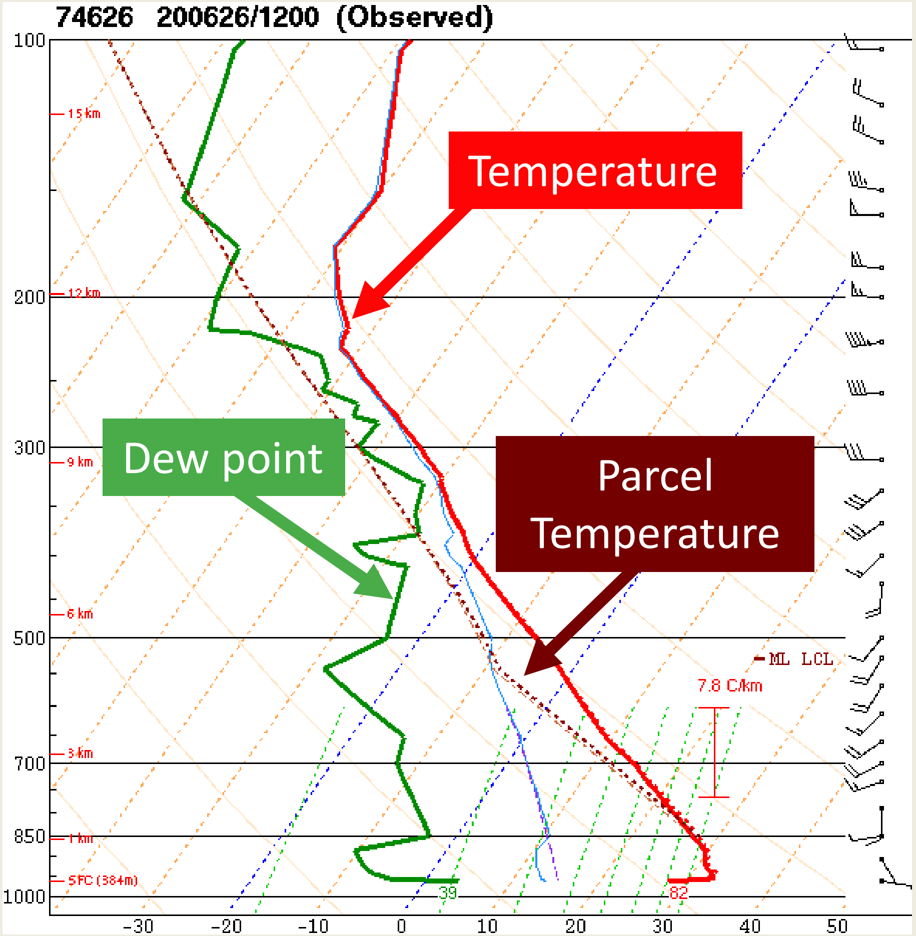
- **CAPE** (**C**onvective **A**vailable **P**otential **E**nergy): measure of instability in the atmosphere
- The larger the CAPE, the greater potential for severe weather
- **CIN** (**C**onvective **In**hibition): often referred to as "opposite CAPE", or the "cap"; amount of energy that will prevent a parcel from rising

CAPE Value (J/kg)	Severe Weather Potential
250-1000	Thunderstorms
1000-2000	Severe Thunderstorms; possibly tornadoes; hail
>2000	Severe weather outbreaks; tornadoes; major wind events; damaging hail

Thunderstorm Ingredients and Skew-T's

Skew T: plot of temperature, dew point, and wind through the atmosphere at a given point

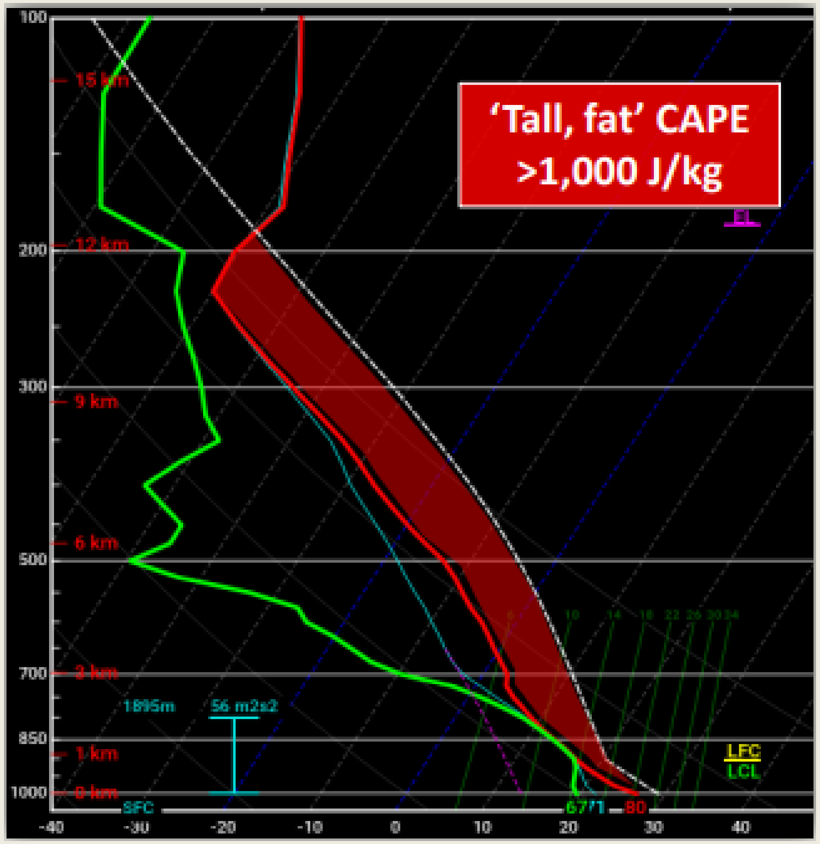
For real-time observed soundings:
https://www.spc.noaa.gov/exper/soundings/

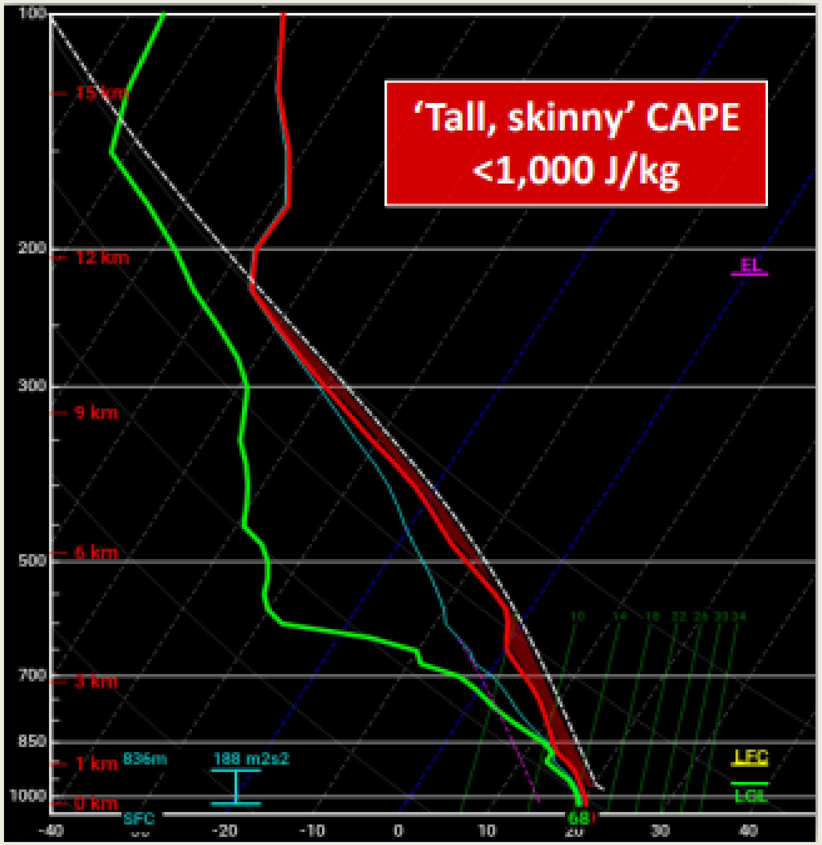


Wind Barbs

Pennant: 50 kts
1 Barb = 10 kts
Half-barb = 5 kts

Instability – Weak vs. Strong CAPE





NWS Birmingham

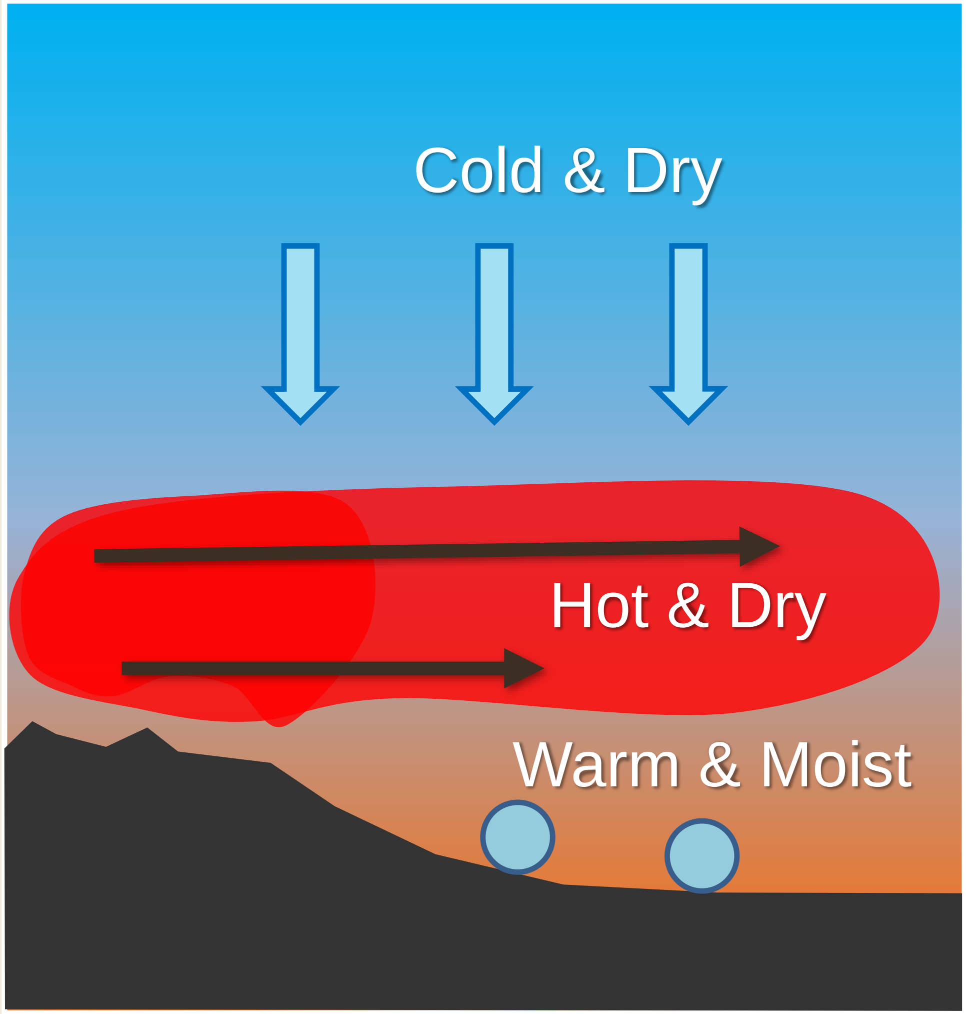
Instability – The Cap (aka CIN)

Cap ("lid") can originate from high terrain or sinking air.

Hot air 2-3 miles above ground creates stable layer.

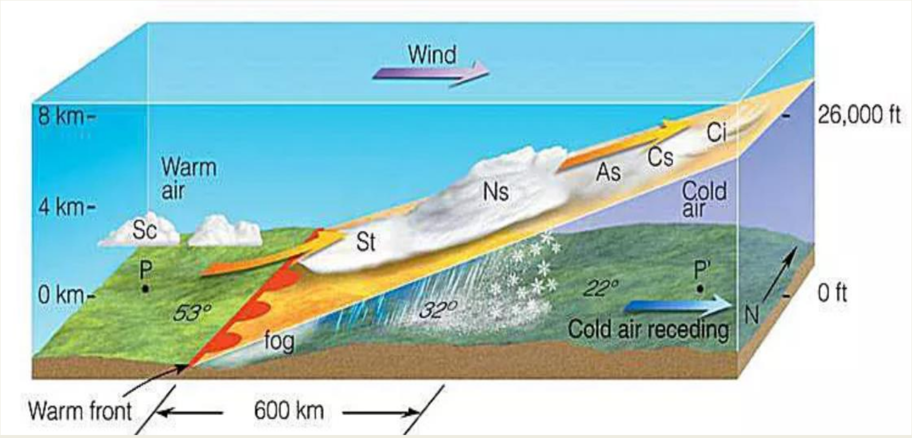
Difficult for rising warm/moist air to break through Cap.

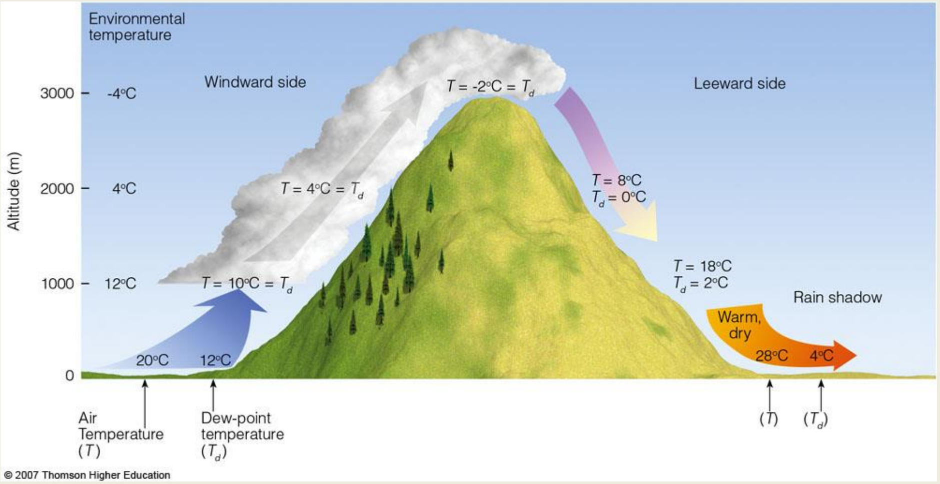
Large scale lift can weaken cap (through cooling and forced ascent).

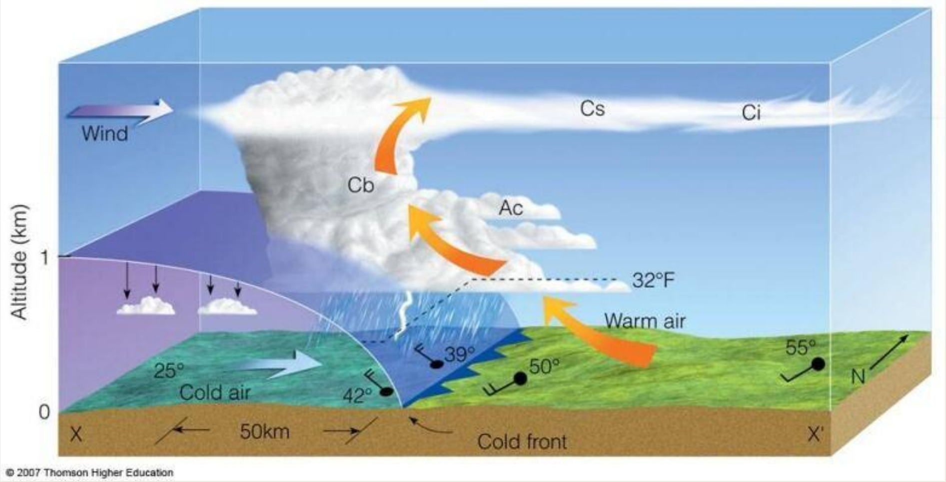


Lift

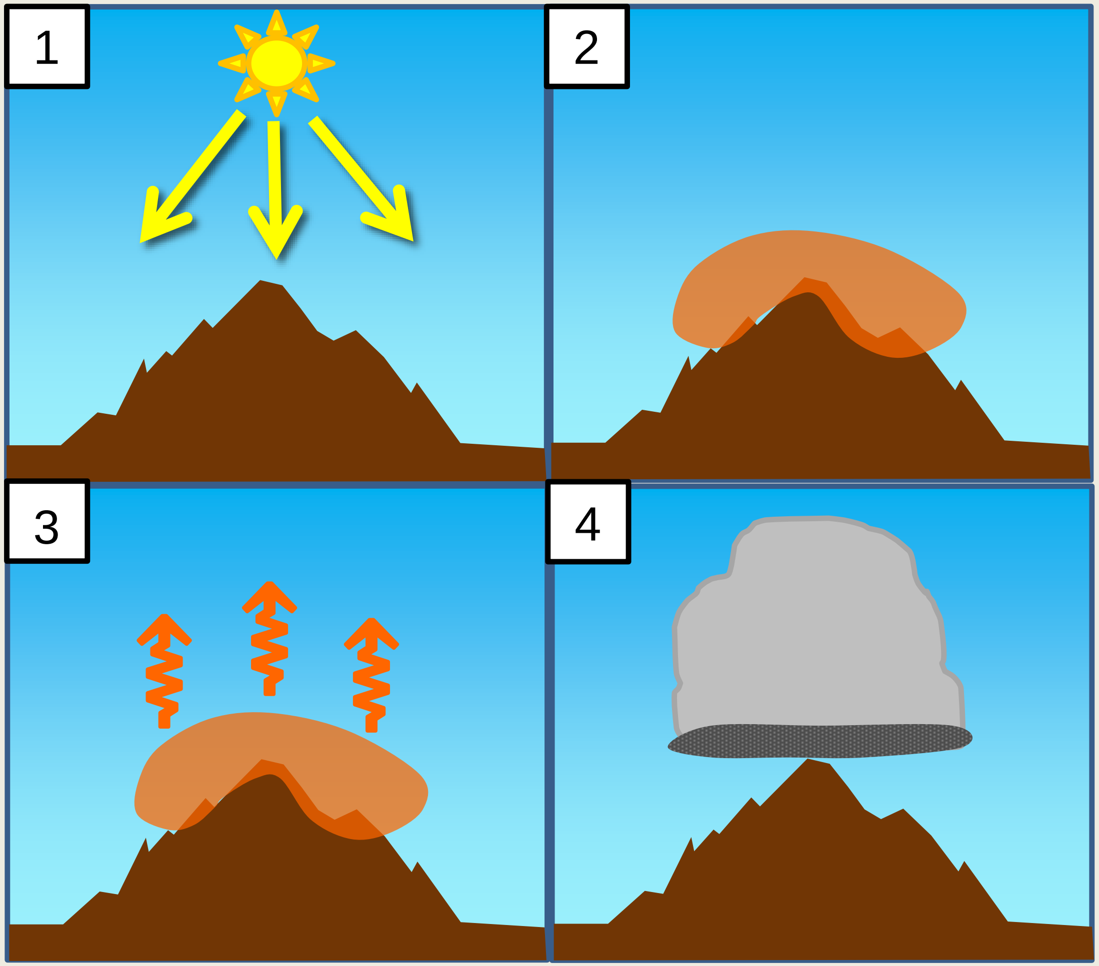
- Lift is necessary to create clouds and thunderstorms
- What are ways air is forced to rise?
  - Mountains
  - Fronts and Boundaries







Lift – Elevated Heat Source



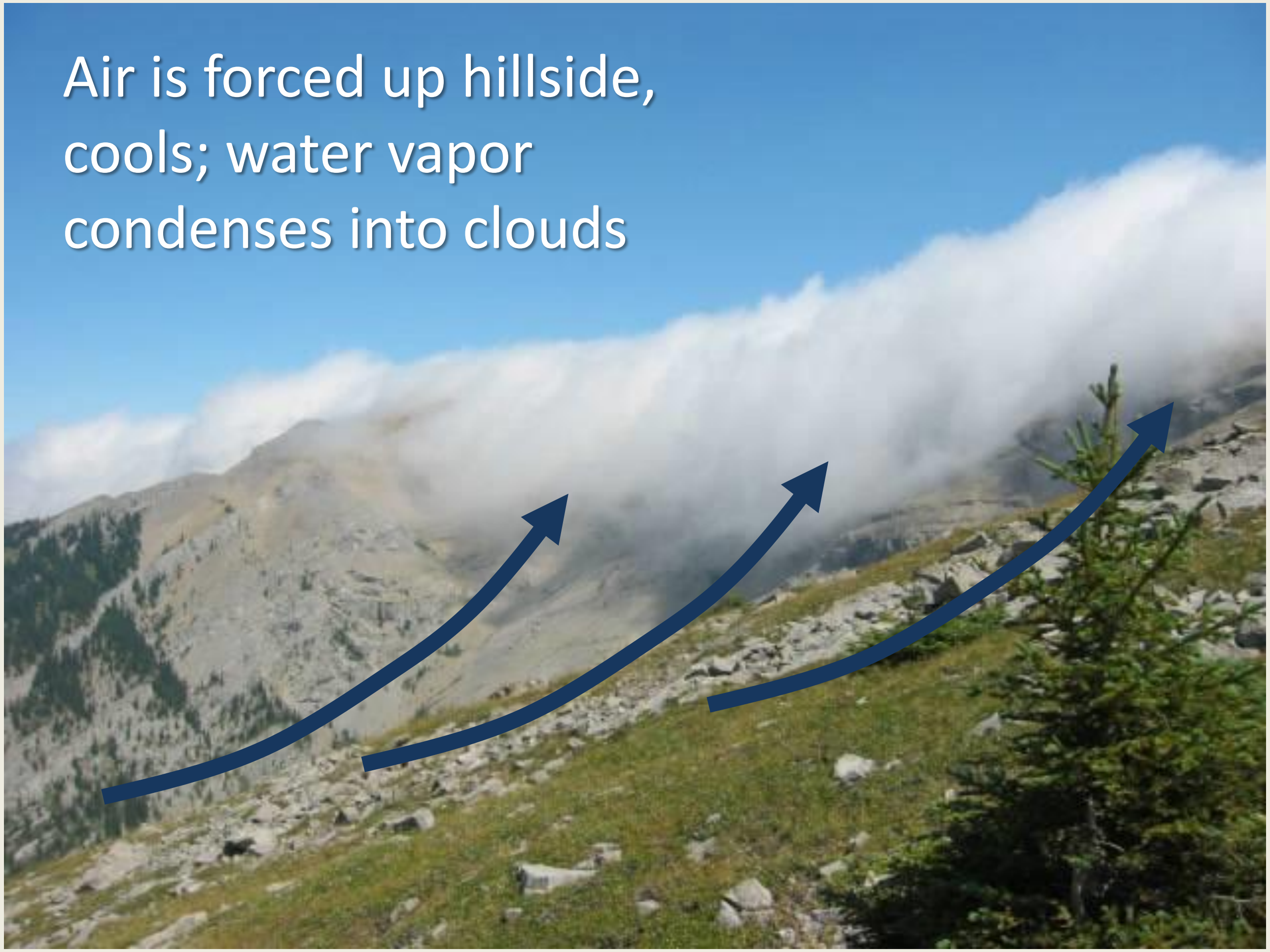
1) Sun heats mountain tops faster than surrounding air

2) Mountains heat air above them

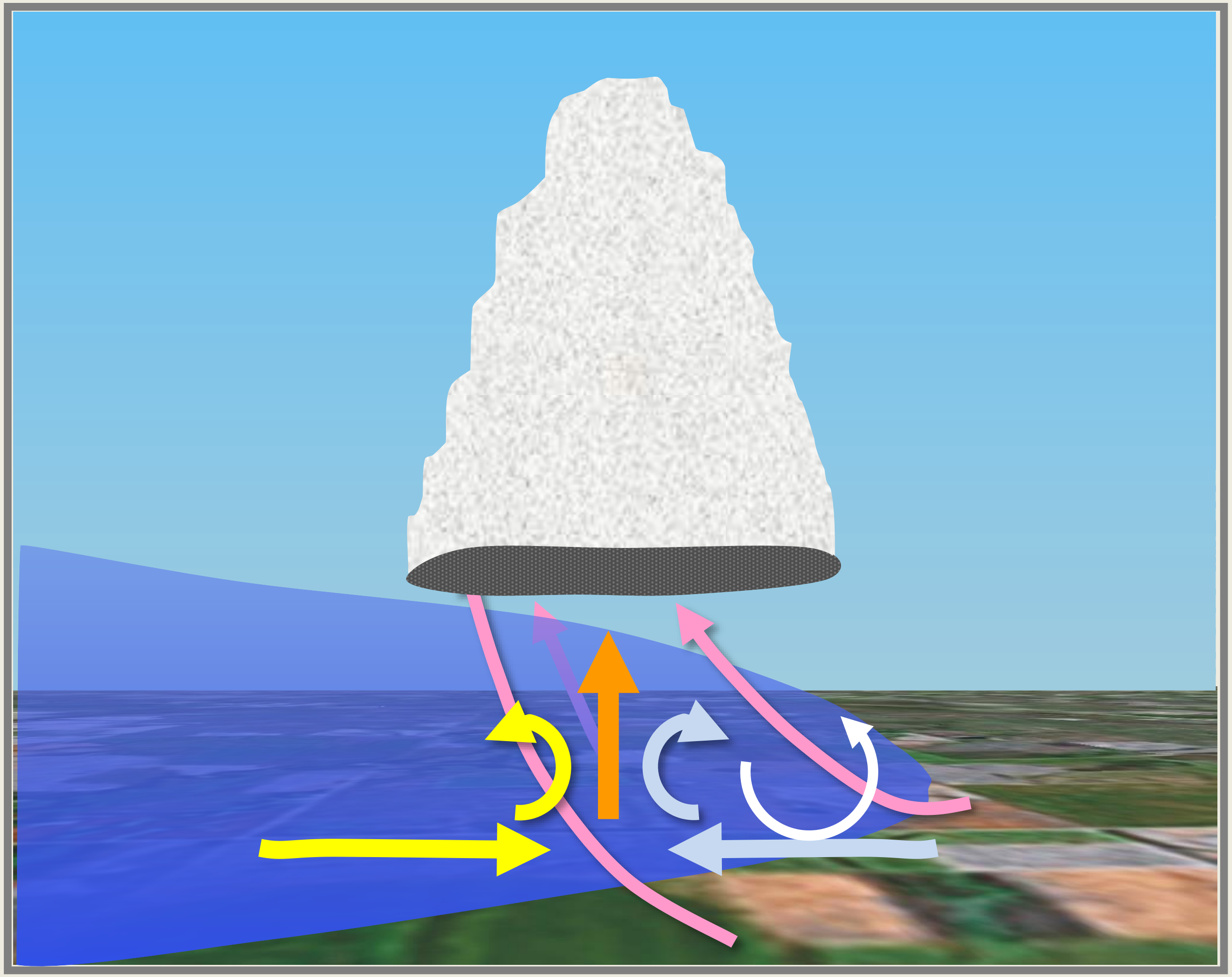
3) Air starts to rise

4) If conditions are favorable, updrafts and thunderstorms can develop

Lift – Upslope Flow



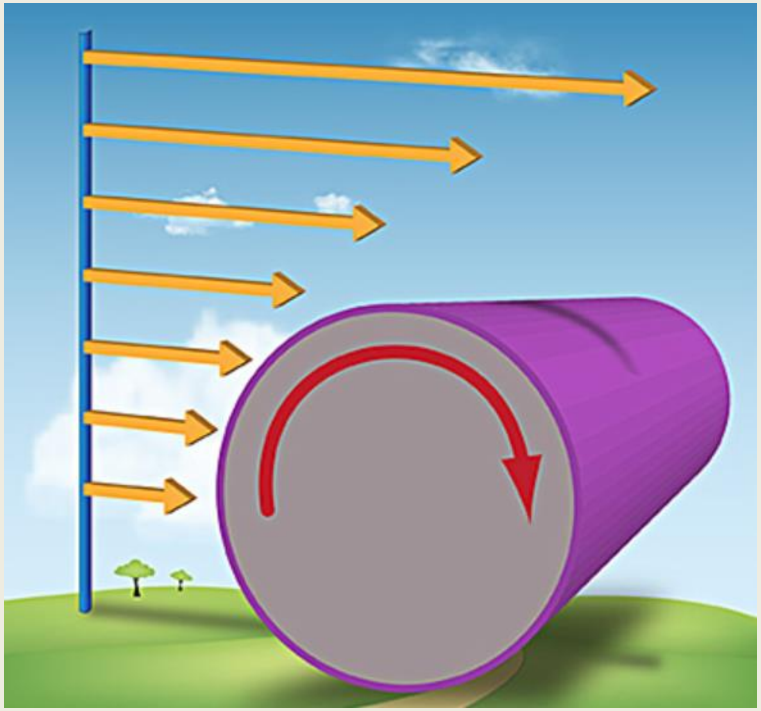
Lift – Fronts & Boundaries

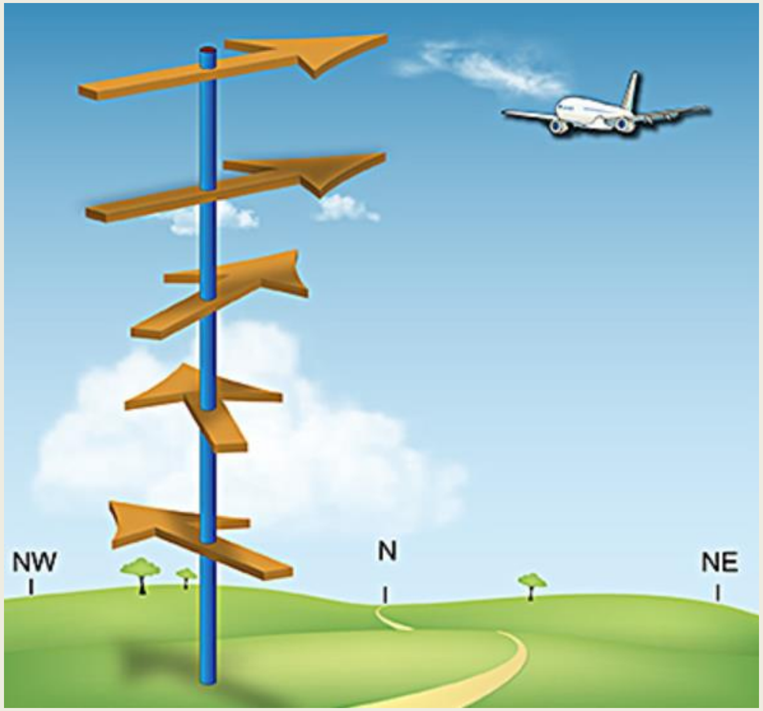


Vertical Wind Shear

- Change of wind direction and/or speed with height
- May have speed shear, directional shear, or both in the atmosphere
  - "Deep Layer" (0-6 km) values of 25+ kts necessary for storm organization
  - 0-6 km vertical wind shear of 35+ kts helpful for mid-level storm rotation
- Crucial in storm organization/lifetime

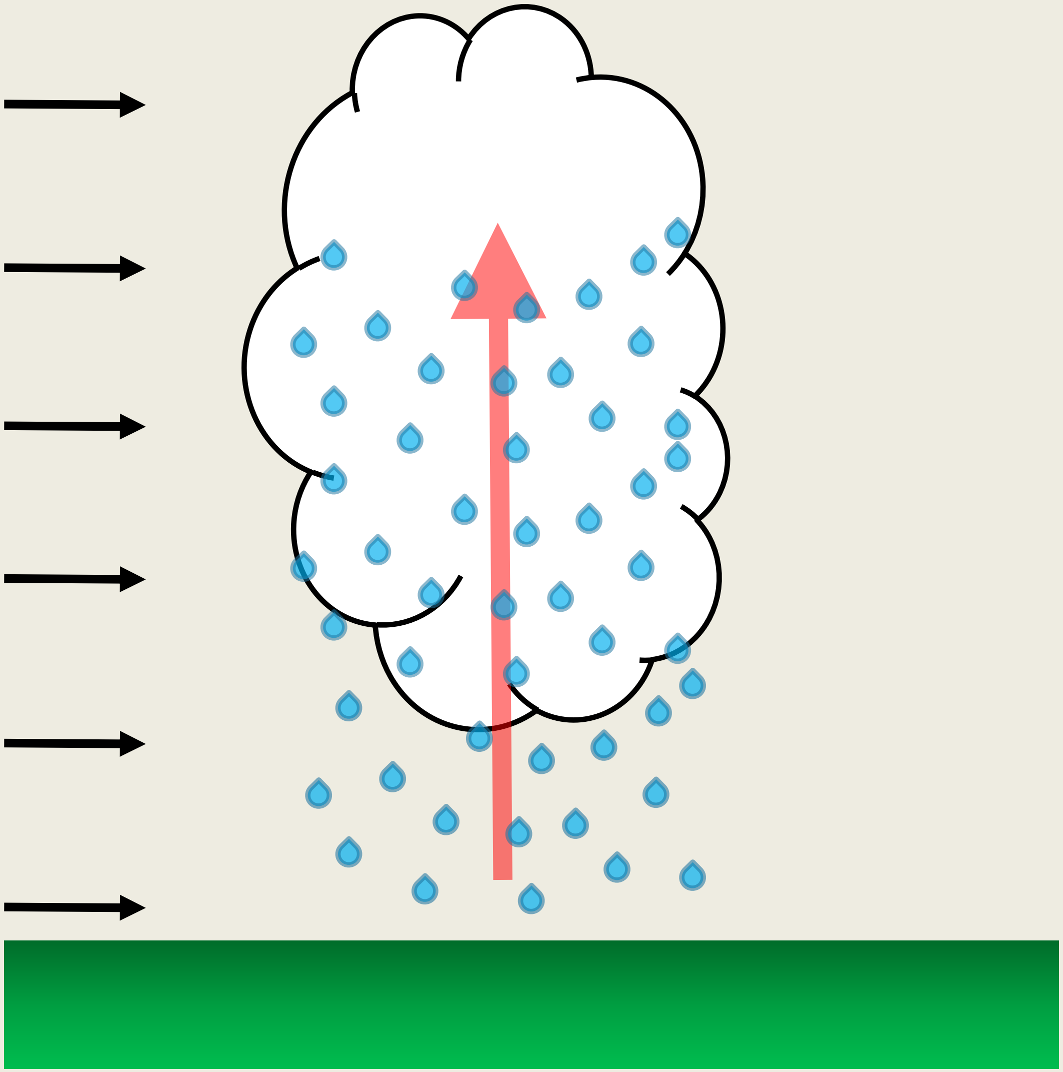
Wind Shear – Types





- Speed Shear
  - Wind **speed** changes with height
- Directional Shear
  - Wind **direction** changes with height

Weak Deep-Layer Shear



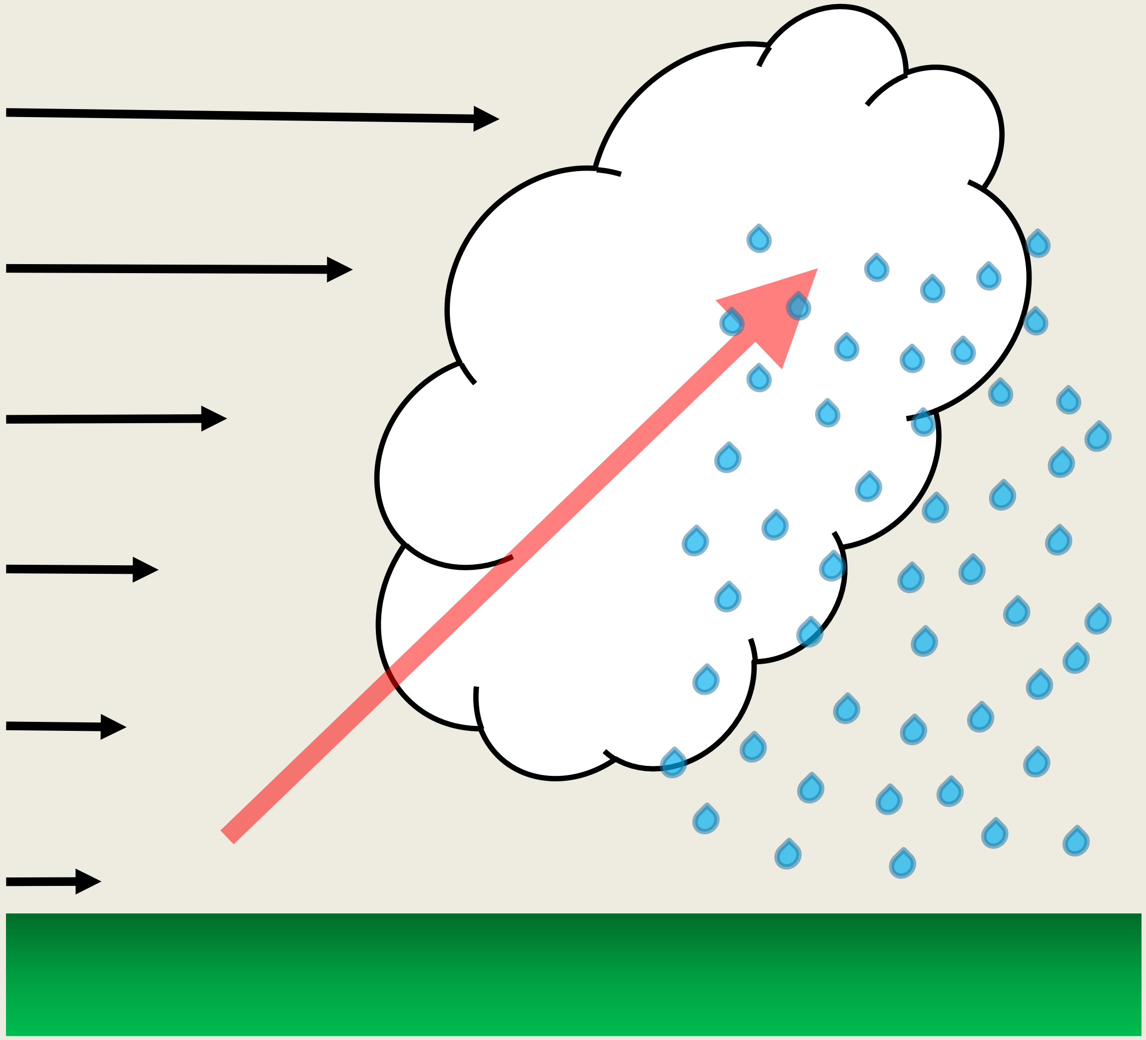
Little change of wind with height

Precip. falls down through updraft

Updrafts are choked, usually short-lived

Outflow can spread out, cut off inflow

Strong Deep-Layer Shear



Ventilates updraft

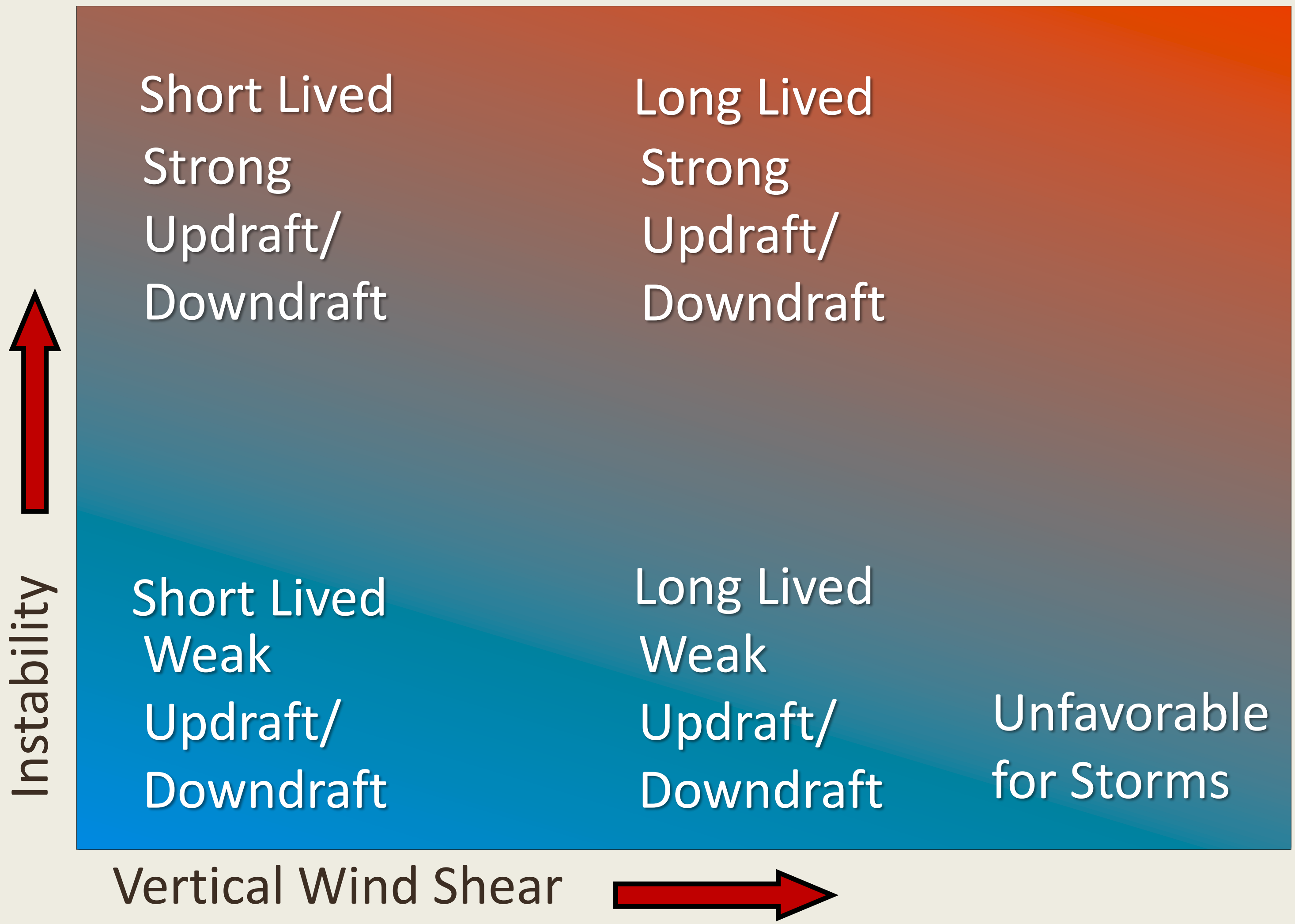
Helps separate updraft/downdraft

Updrafts and downdrafts can live longer

Can induce mid-level rotation

Can we have too much shear?

Instability and Vertical Shear



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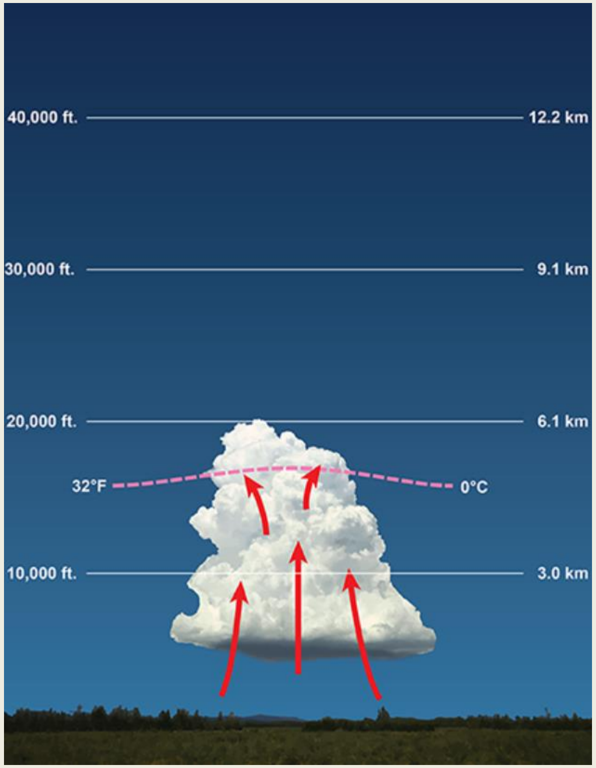
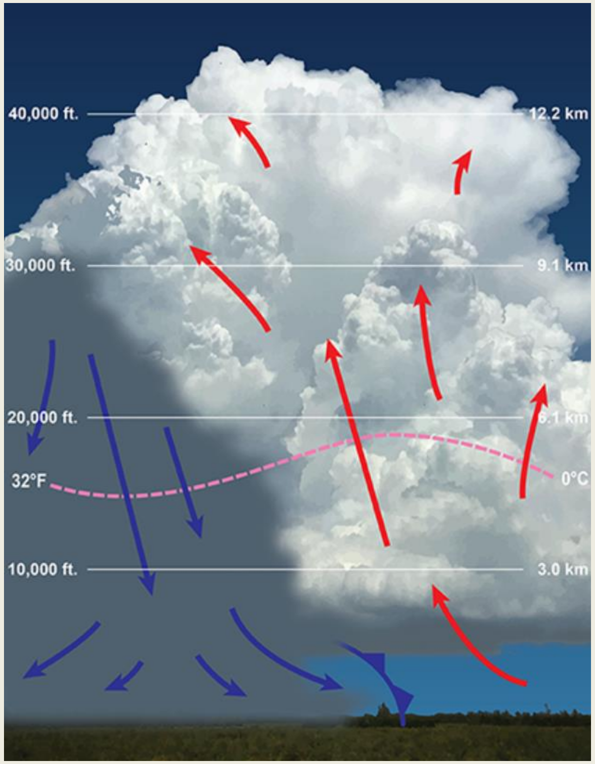
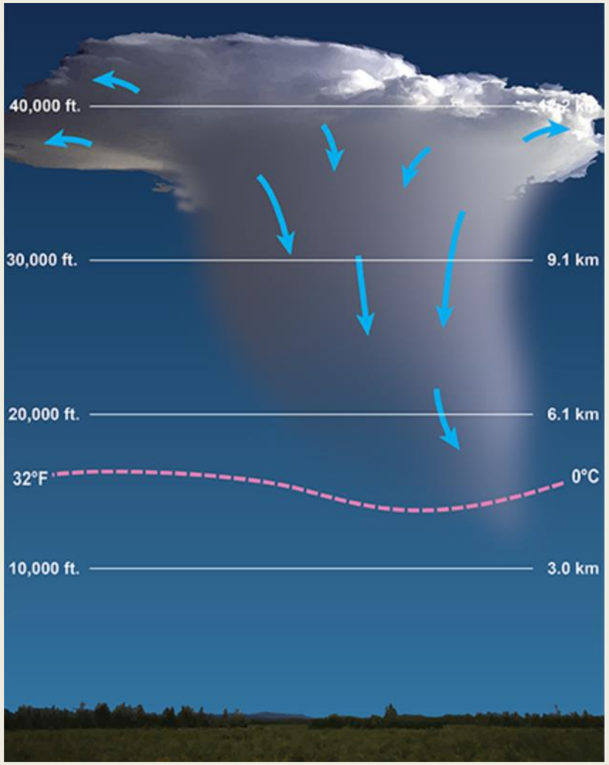
Ordinary Thunderstorms



Towering Cumulus

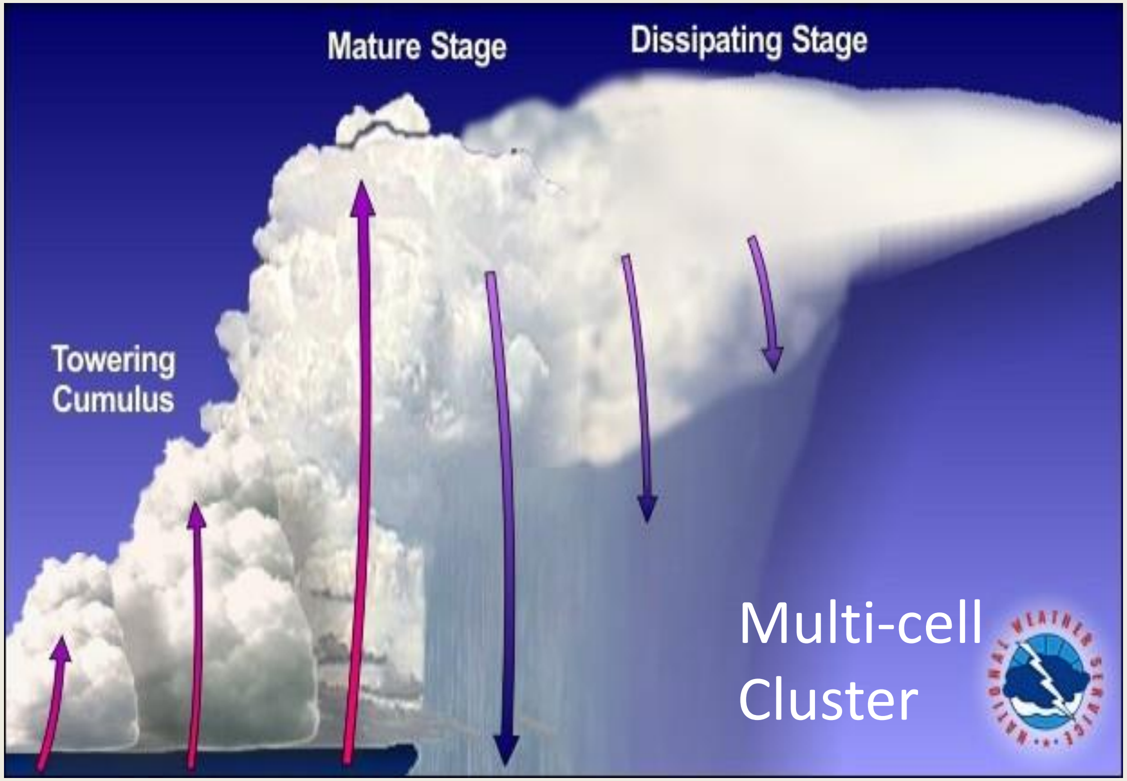


Mature Stage



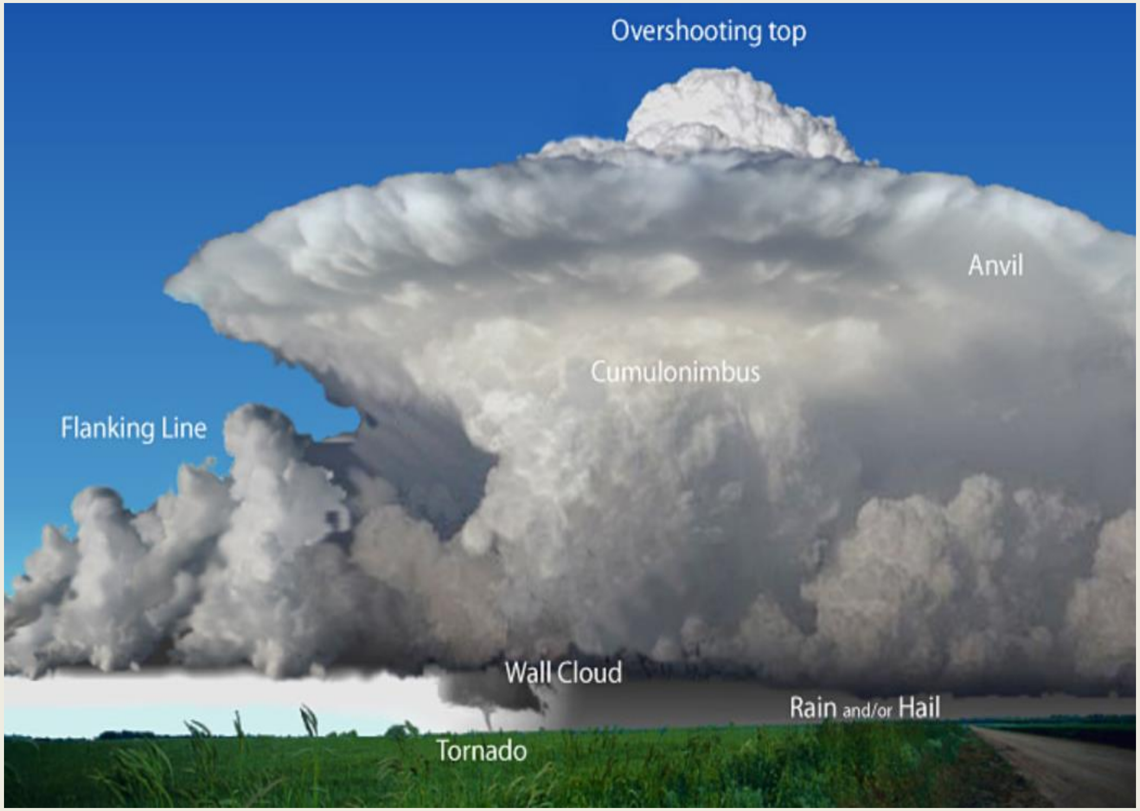
Dissipation

Multi-cell Thunderstorms



- As the initial cell matures, upper level winds carry it downstream
- At the same time, a new cell forms upwind to take its place
- If upper-level winds are opposite of low-level winds, **backbuilding** can develop
  - This can lead to flash flooding

Supercell Thunderstorms



- Virtually all supercells are severe
- Supercells can attain updraft speeds over 100 mph and dangerous downbursts
- Supercells are responsible for nearly all tornadoes in the U.S.
- Tornadoes are most likely to occur in a supercell that has winds turning clockwise with height (veering)
- Can produce extreme rainfall: **flash flood threat**

Supercells

Mesocyclone

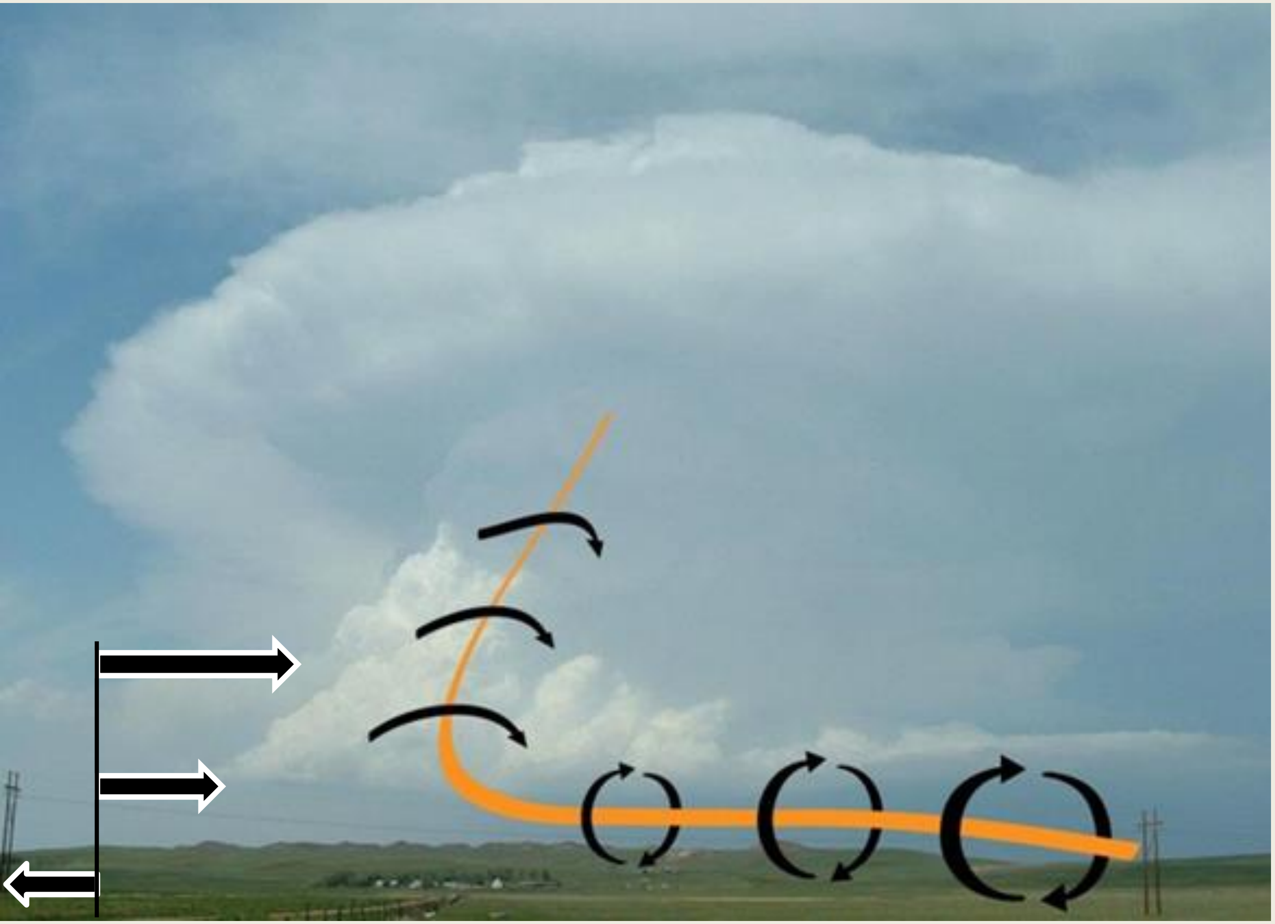
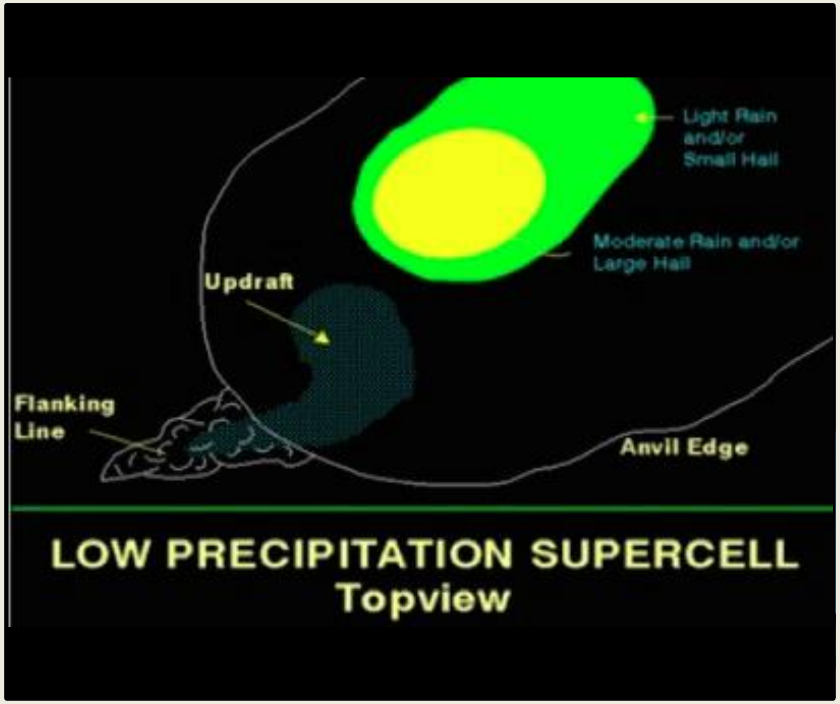


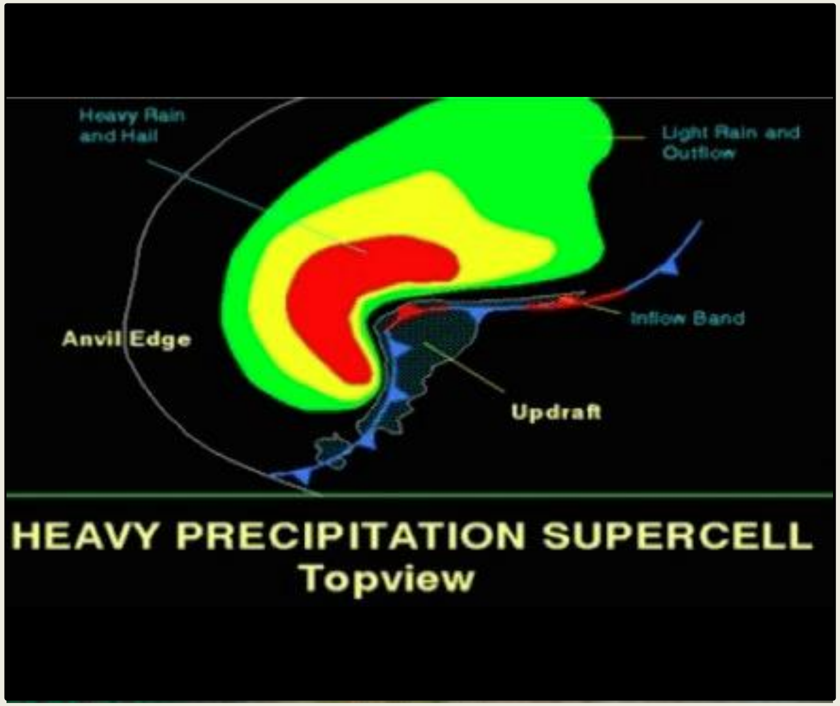
Photo: Markowski and Robinson (2010)

- Tilting of horizontal vorticity by updraft
- Maximum updraft -> maximum tilting -> maximum rotation at mid-levels
- Mid-level (relative) low pressure accelerates updraft
- Can produce stronger updrafts than thermodynamics alone

Types of Supercells



Low-Precip (LP) Supercells



High-Precip (HP) Supercells

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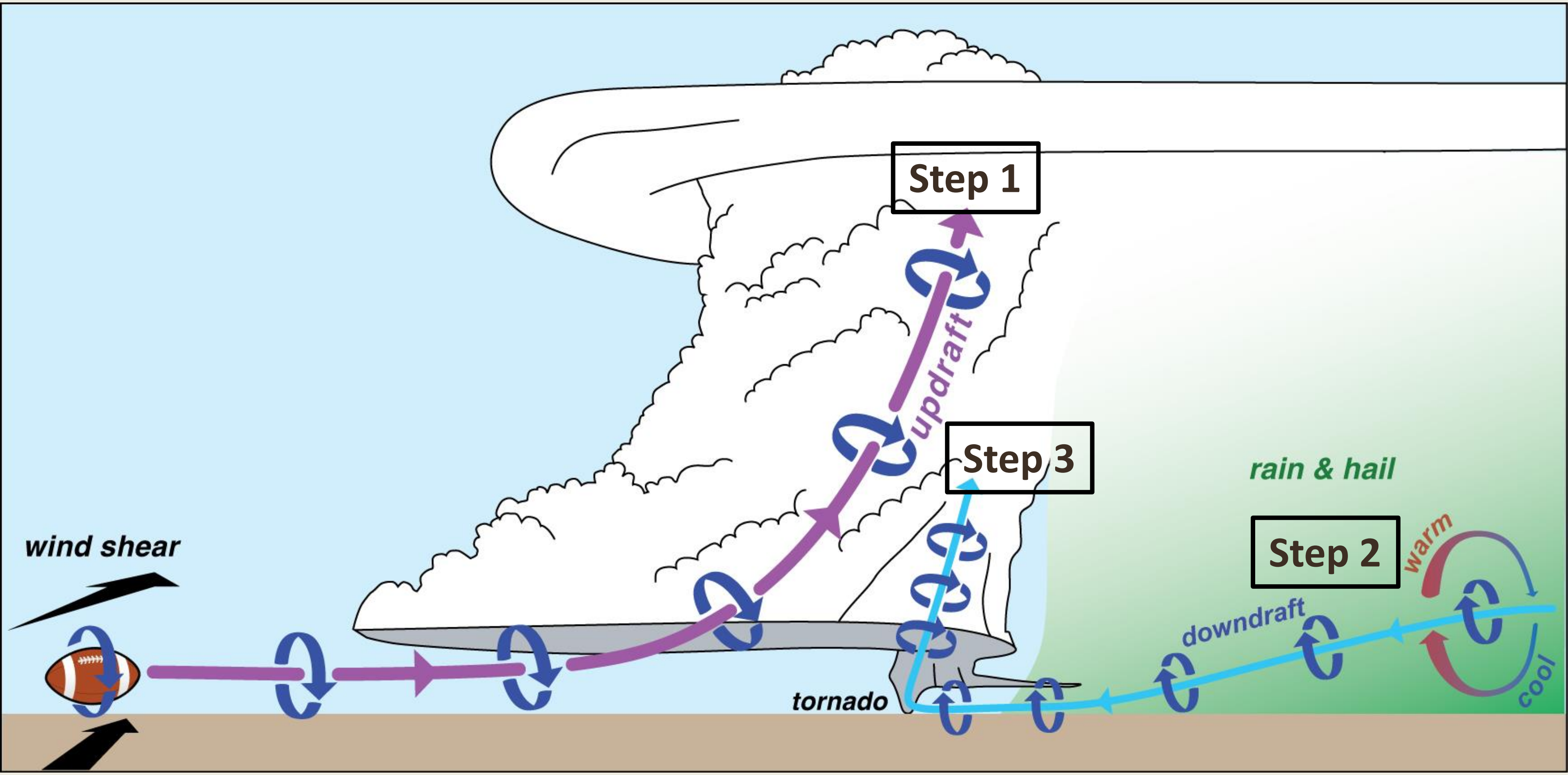
Tornadoes - Tornadogenesis

3 step process to tornado formation

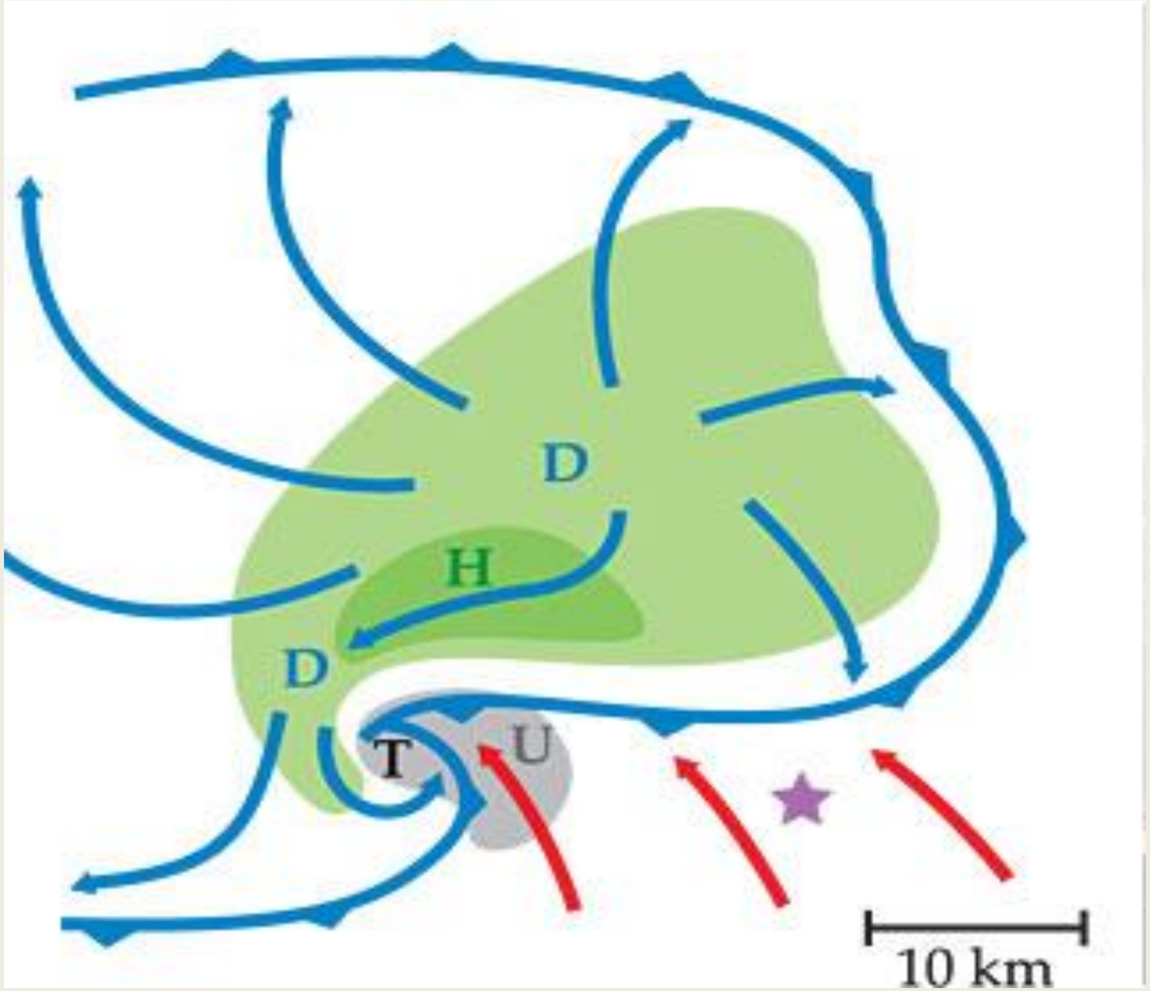
1. Wind shear causes horizontal spin to be tilted vertically when it is pulled into the updraft. This causes mid-level rotation, this is not strong enough for a tornado to form.
2. Temperature differences along the edge of the rain-cooled downdraft provides another source of horizontal spin with air moving from the downdraft toward the updraft.
3. If the air within the downdraft is not too cold (too dense), spinning air can be tilted vertically and stretched by the updraft leading to the formation of a tornado.

Tornadoes - Tornadogenesis



Images: https://sites.psu.edu/tornadoes/

Tornadoes - Tornadogenesis



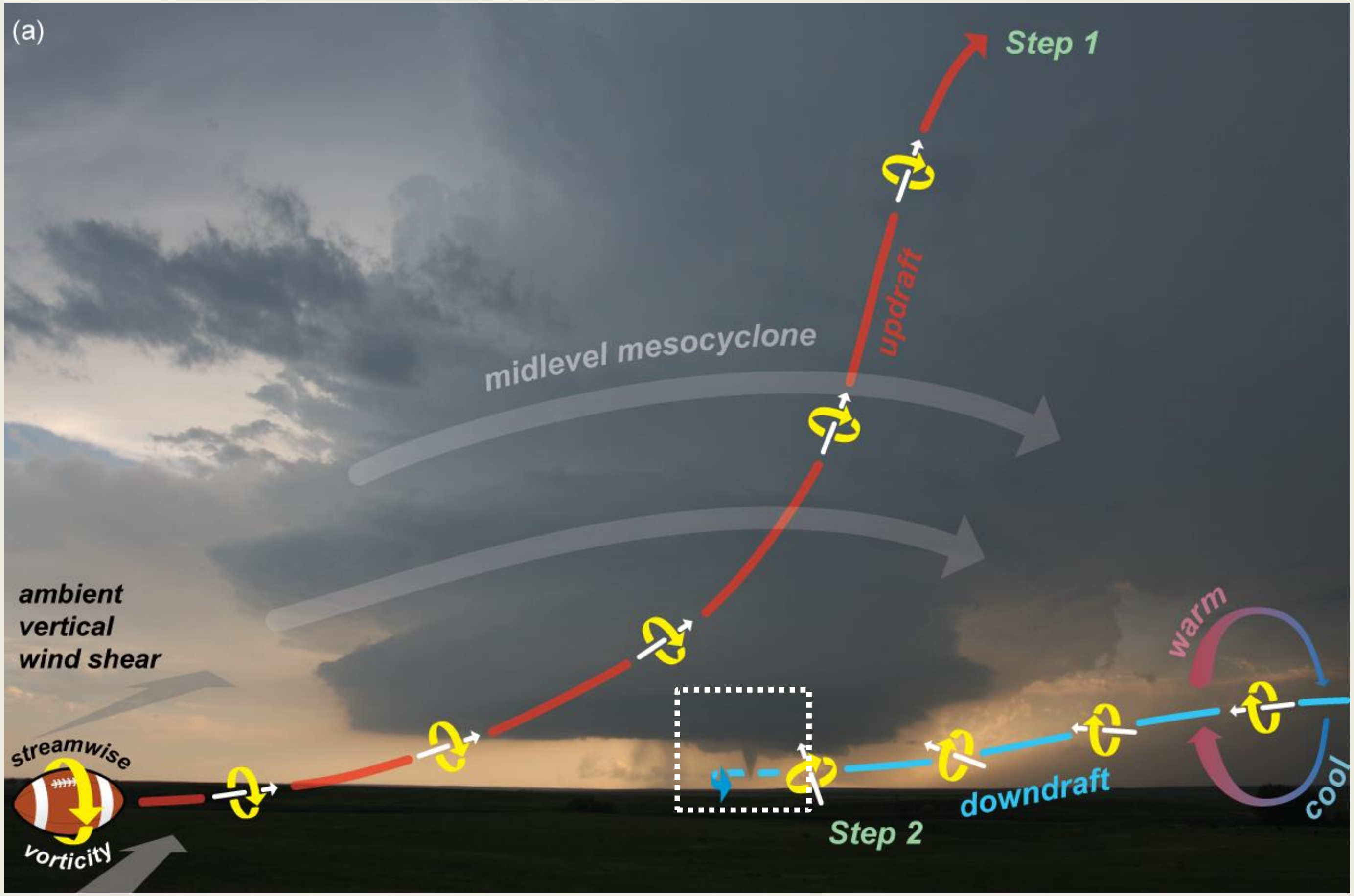
Tornadic Supercell – Top View

“D” = Downdraft
“H” = Hail area
“U” = Updraft
“T” = Tornado

Images: Physics Today - Markowski and Richardson (adapted from Lemon and Doswell)

Tornadoes - Tornadogenesis

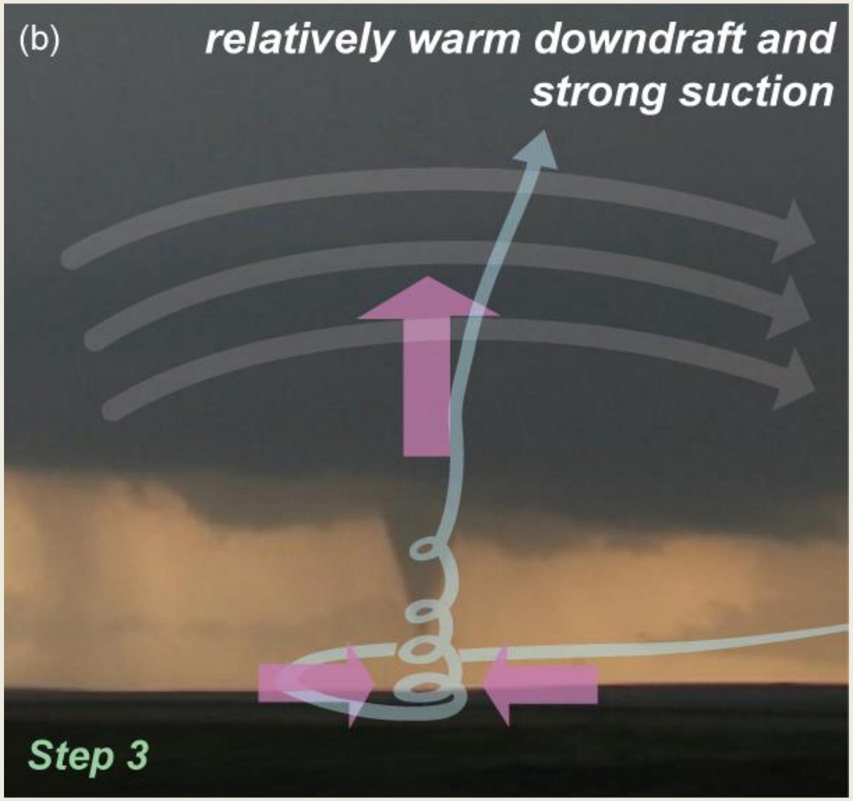
Steps 1 & 2



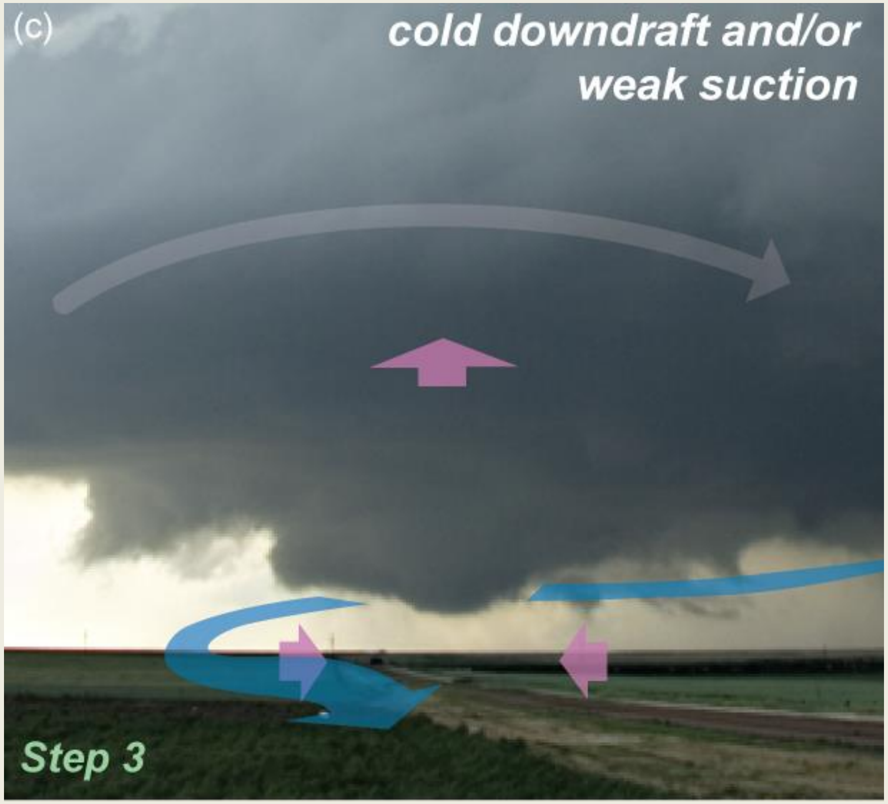
Images: https://sites.psu.edu/tornadoes/

Tornadoes - Tornadogenesis

Step 3 - Tornado



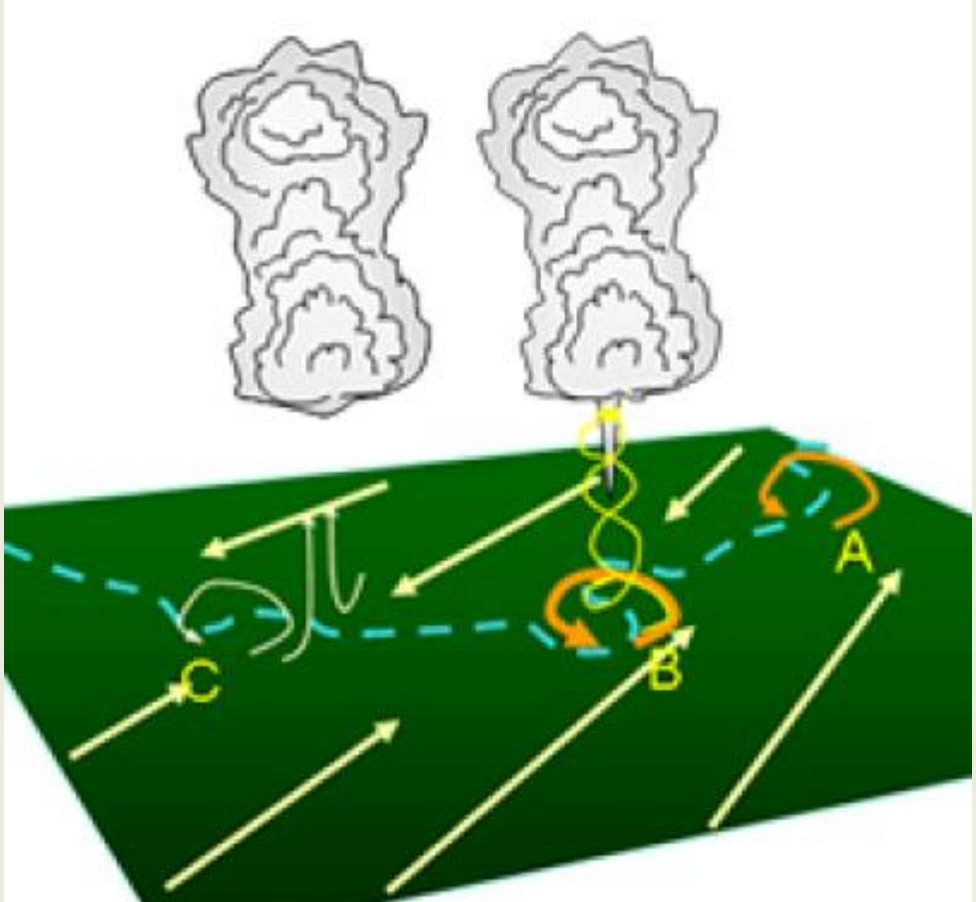
Step 3 – No Tornado



Images: https://sites.psu.edu/tornadoes/

Landspouts – Formation

Non-Supercell



From Szoke et al. (1984)

A – convergence/ shear along stationary boundary. No updraft, no tornado

B – strengthening updraft stretches shear/rotation into tornado

C – updraft and shear not colocated, no tornado

Landspouts

Paul Mueller

Gina Chavez-Smith

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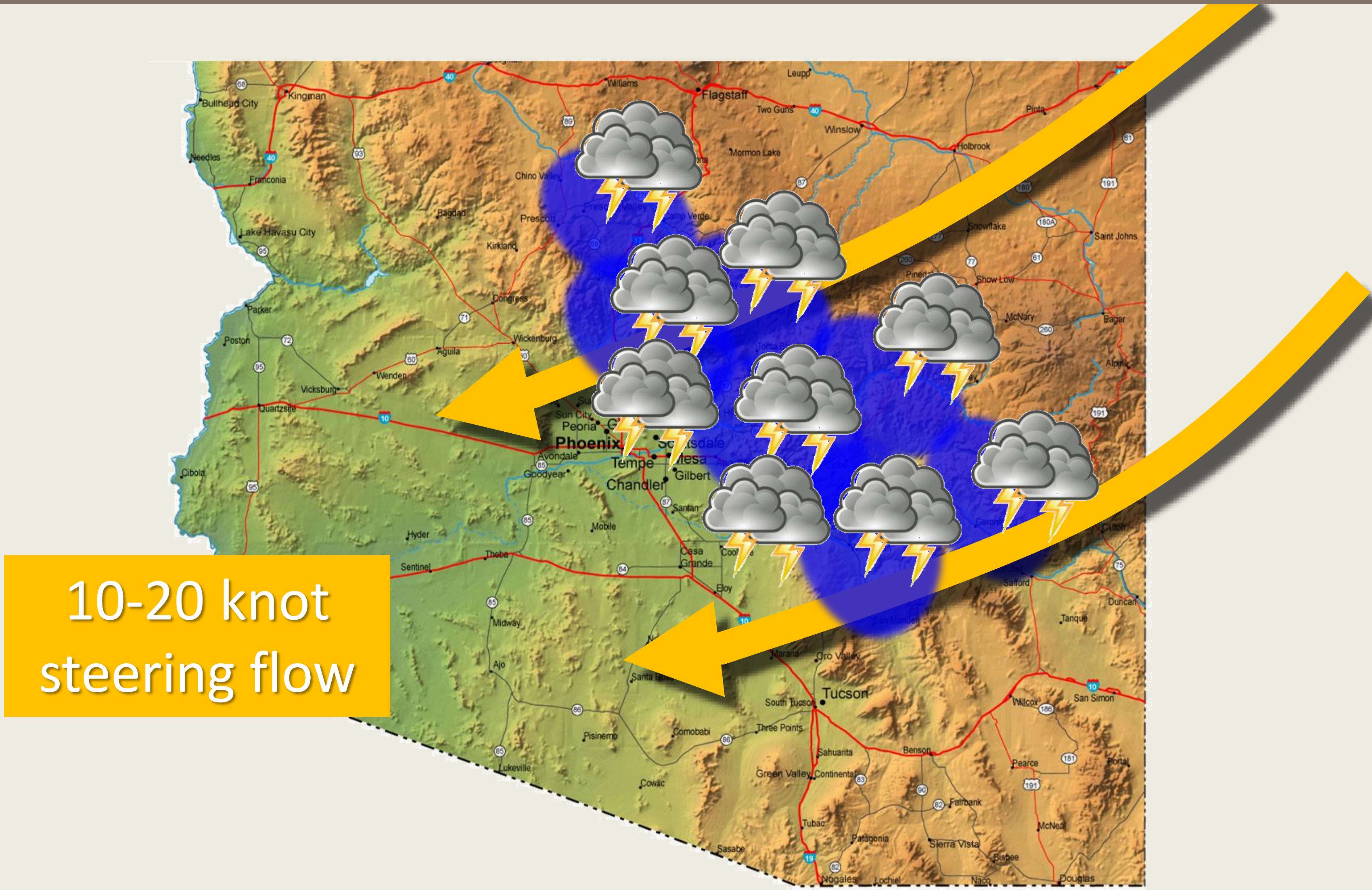
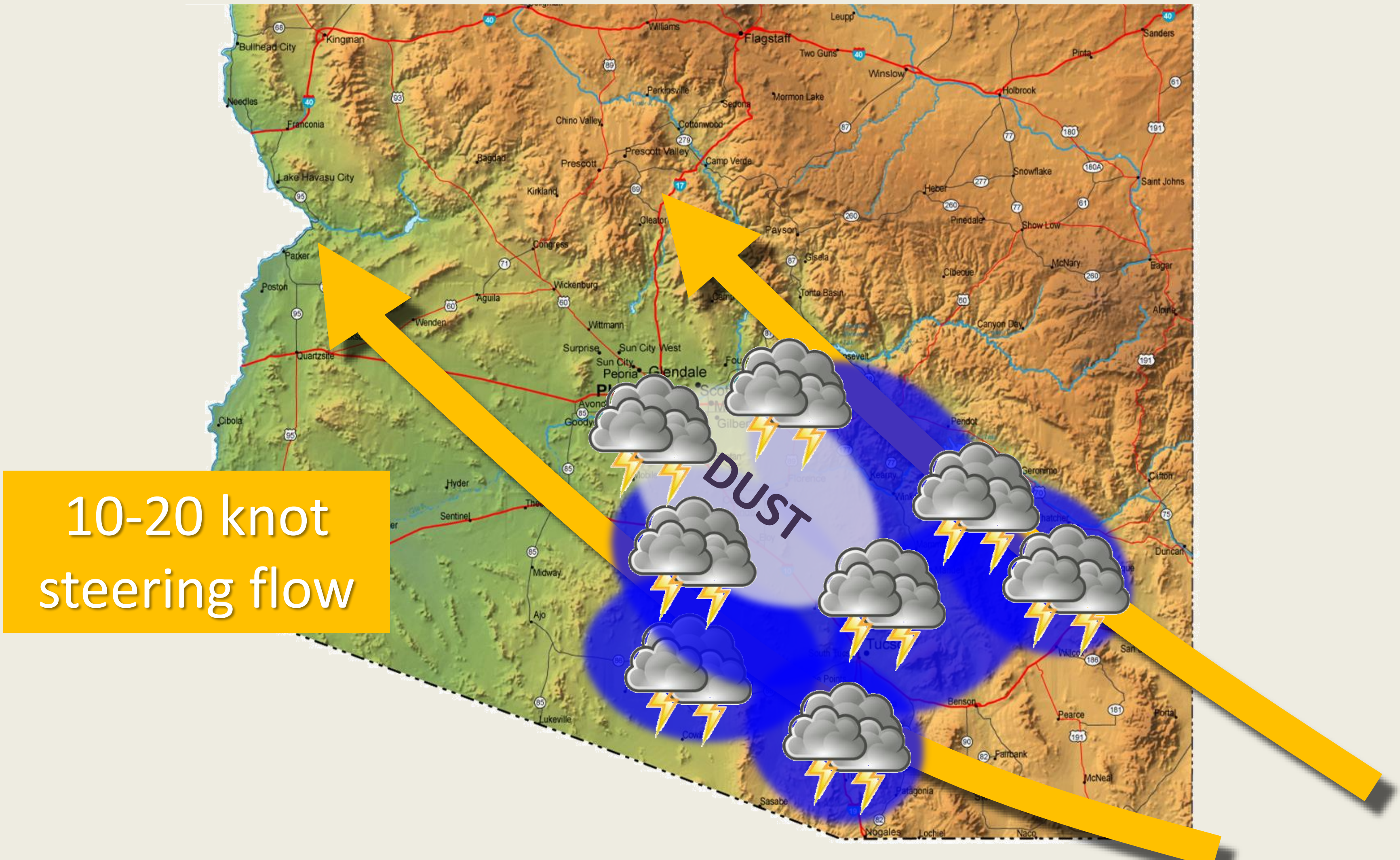
Monsoon Storm Evolutions

- Usually weak steering flow from the southeast
- Initial storm development over high terrain of Mogollon Rim and/or southern Arizona
- Outflows move toward lower desert
- Development of storms over lower deserts dependent on available CAPE, breakable CIN, strength of lift along gust front/cold pool
- Stronger shear or presence of larger-scale lift may enhance storm organization and lifetime

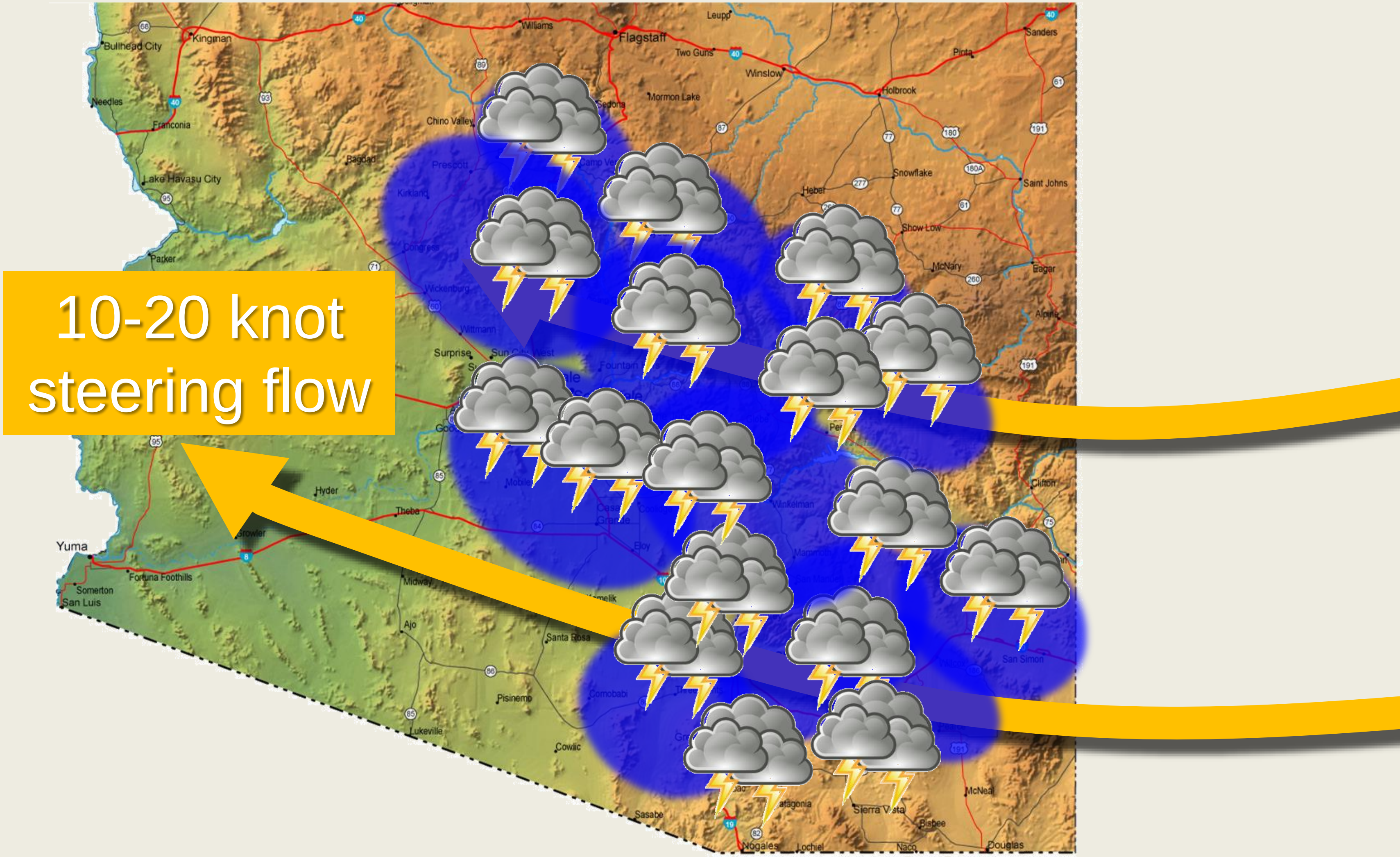
Mongollon Rim Storm Evolution



Southern Arizona Storm Evolution

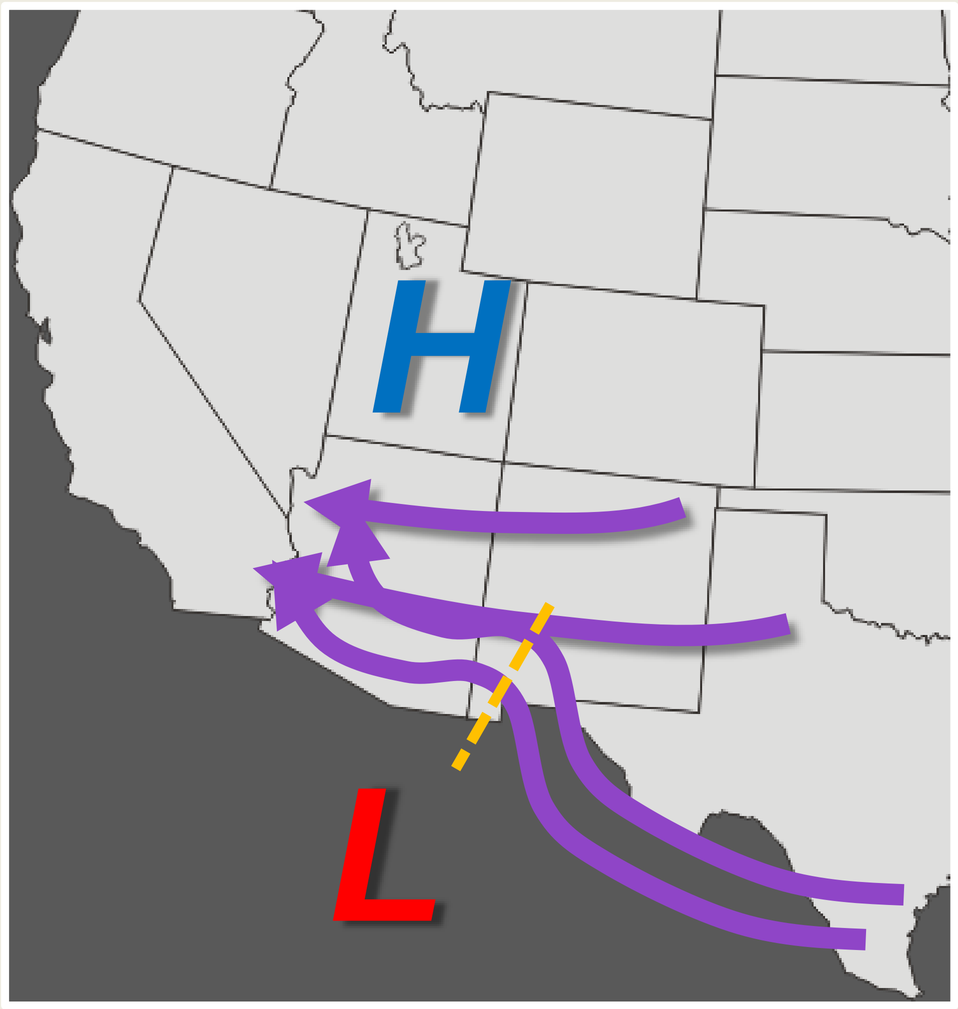


Combined Storm Evolution



/NWSPhoenix @NWSPhoenix /NWSPhoenix www.weather.gov/psr

“Enhanced ” Monsoon Events

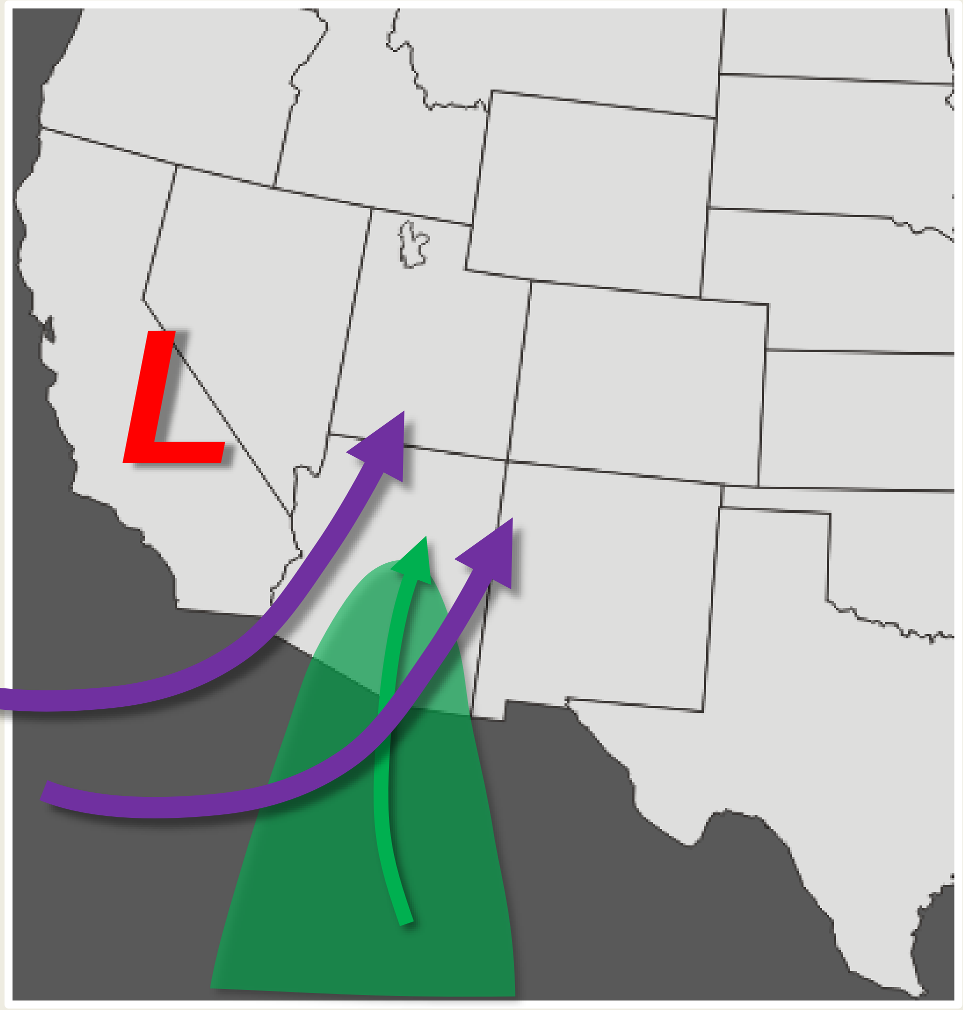


Subtropical waves (inverted troughs, easterly waves) can provide large-scale lift

Lift can help overcome shortcomings in the environment

If upper high shifts over Great Basin area, increased gradient can enhance deep-layer shear

“Transition” Event



As monsoon ends (High retreats southward), residual moisture remains in place

Upper level system in the Westerlies affects the southwest U.S.

Moisture, shear patterns resemble springtime plains events

Highly organized/severe storms are possible

Photo: Mike Oblinski Photography

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Storm Prediction Center

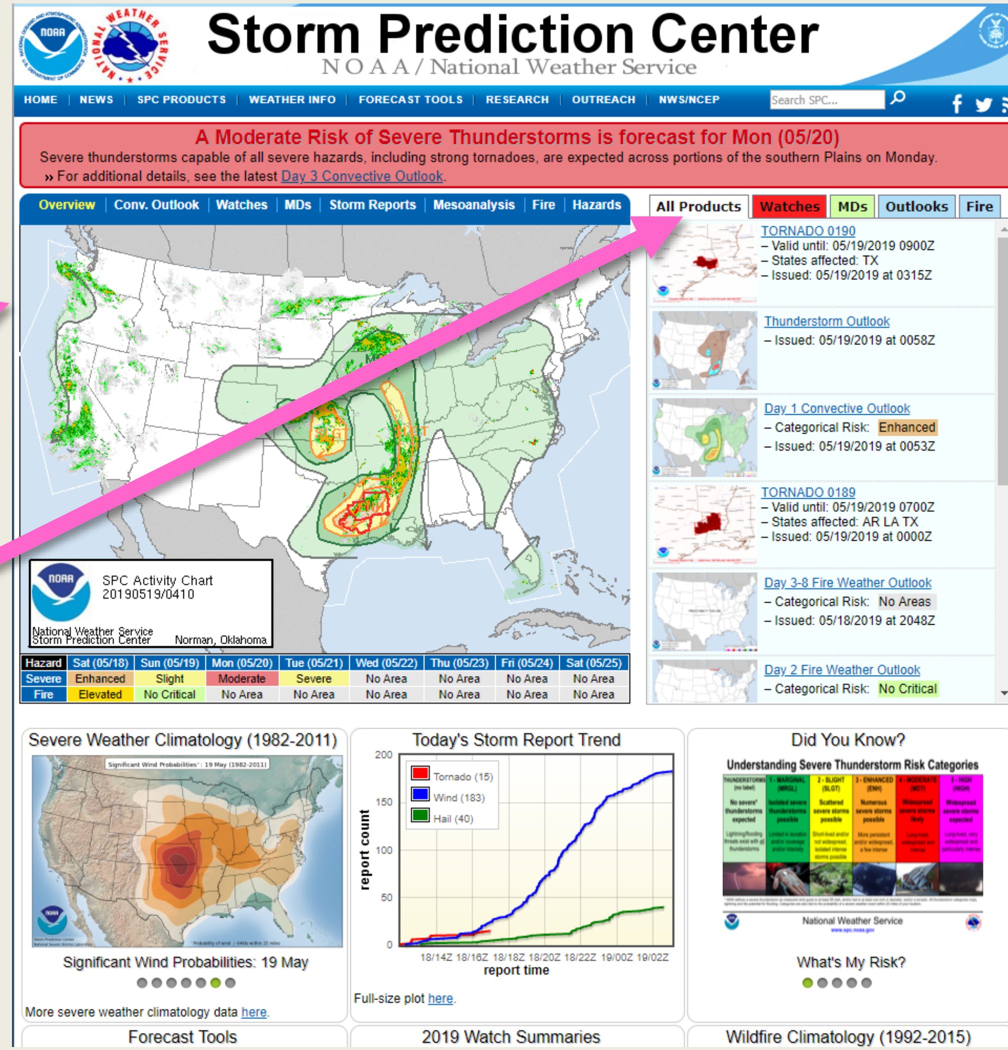
www.spc.noaa.gov

Headlines and drop-down menus

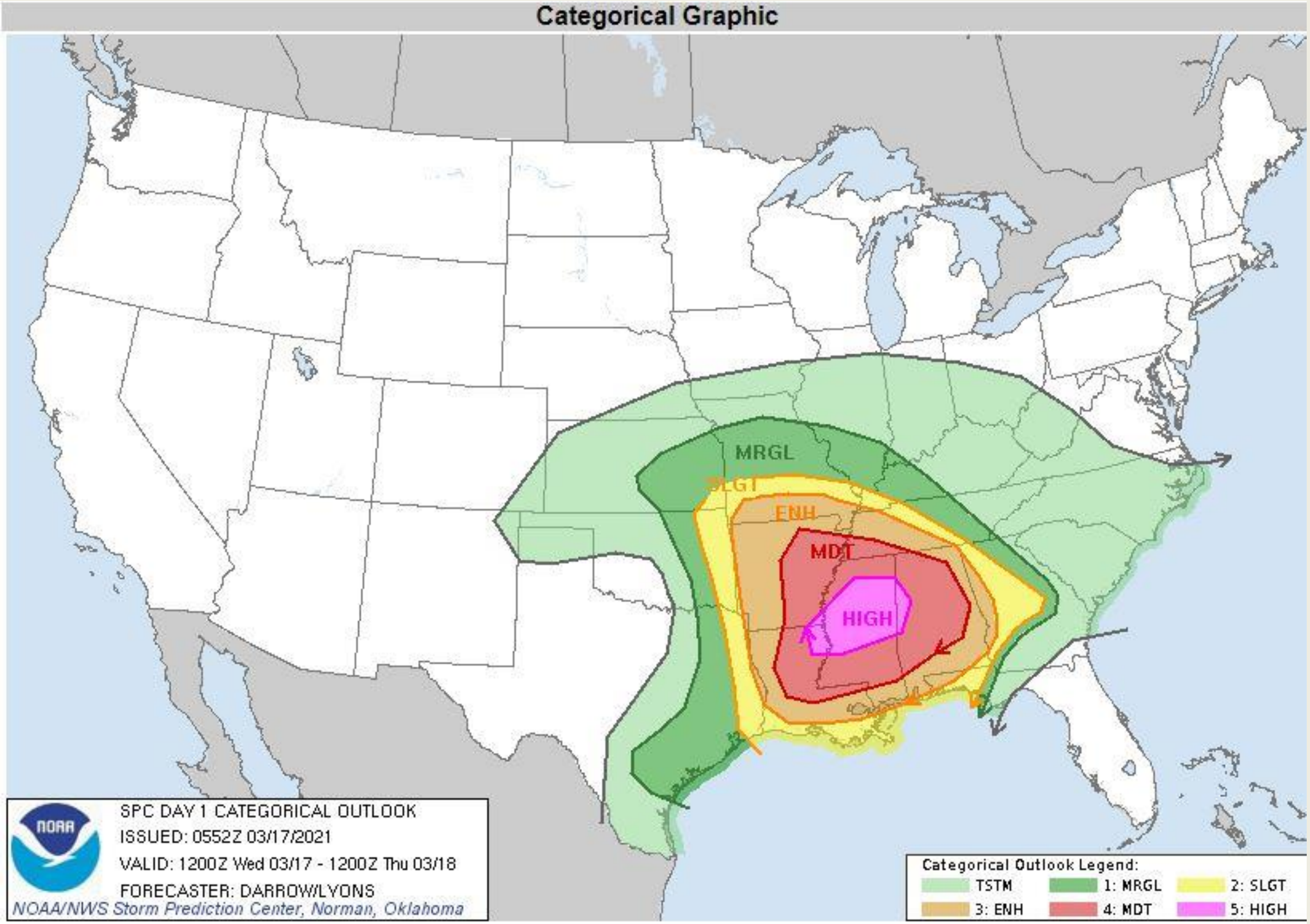
Mouse over to see individual maps

Recently-issued information

Climatology maps and report trends



SPC Convective Outlook - example



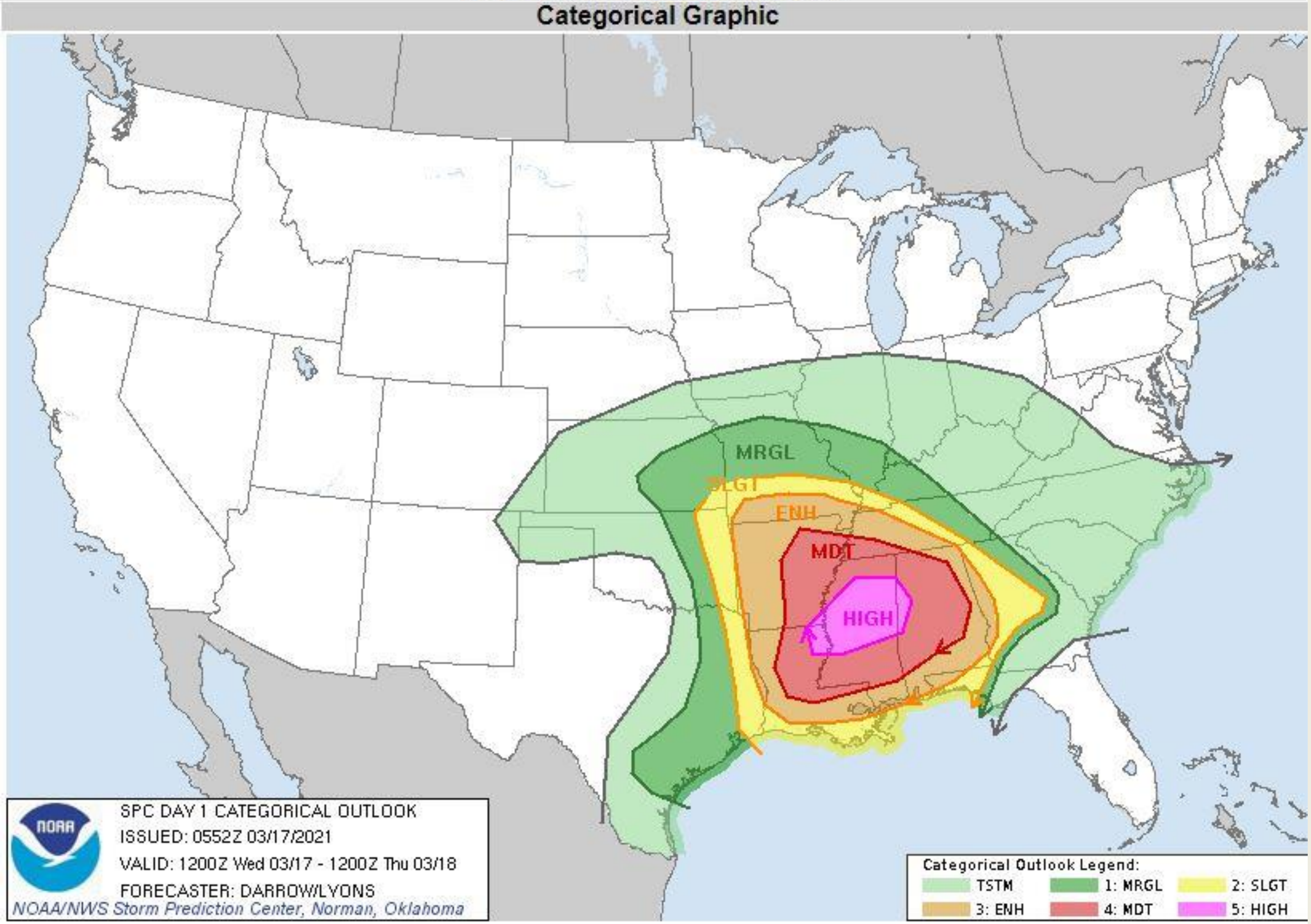
SPC Convective Outlook

Risk Categories

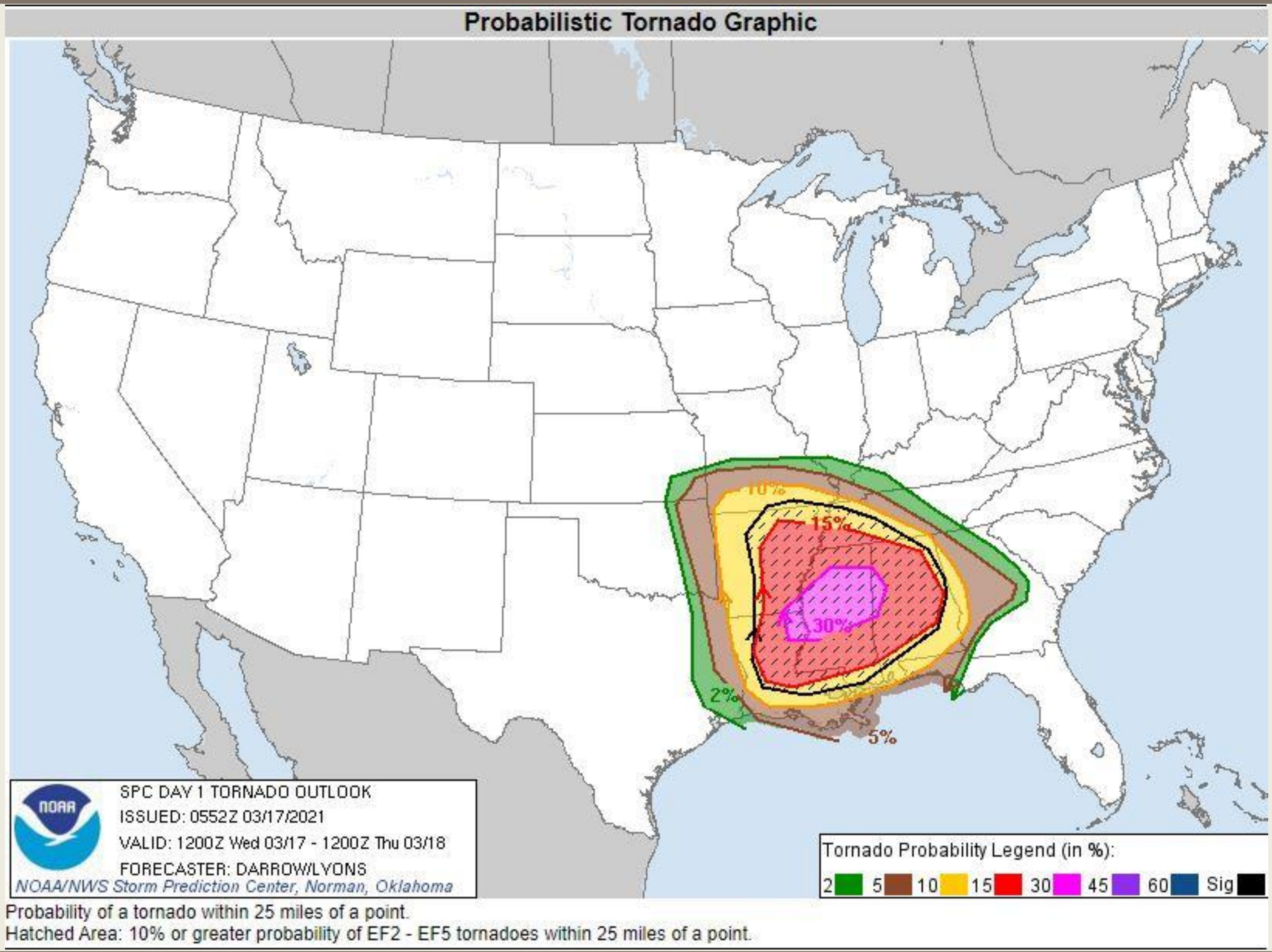
Understanding Severe Thunderstorm Risk Categories

THUNDERSTORMS (no label)	1 - MARGINAL (MRGL)	2 - SLIGHT (SLGT)	3 - ENHANCED (ENH)	4 - MODERATE (MDT)	5 - HIGH (HIGH)
No severe* thunderstorms expected	**Isolated severe thunderstorms possible**	**Scattered severe storms possible**	**Numerous severe storms possible**	**Widespread severe storms likely**	**Widespread severe storms expected**
Lightning/flooding threats exist with all thunderstorms	Limited in duration and/or coverage and/or intensity	Short-lived and/or not widespread, isolated intense storms possible	More persistent and/or widespread, a few intense	Long-lived, widespread and intense	Long-lived, very widespread and particularly intense

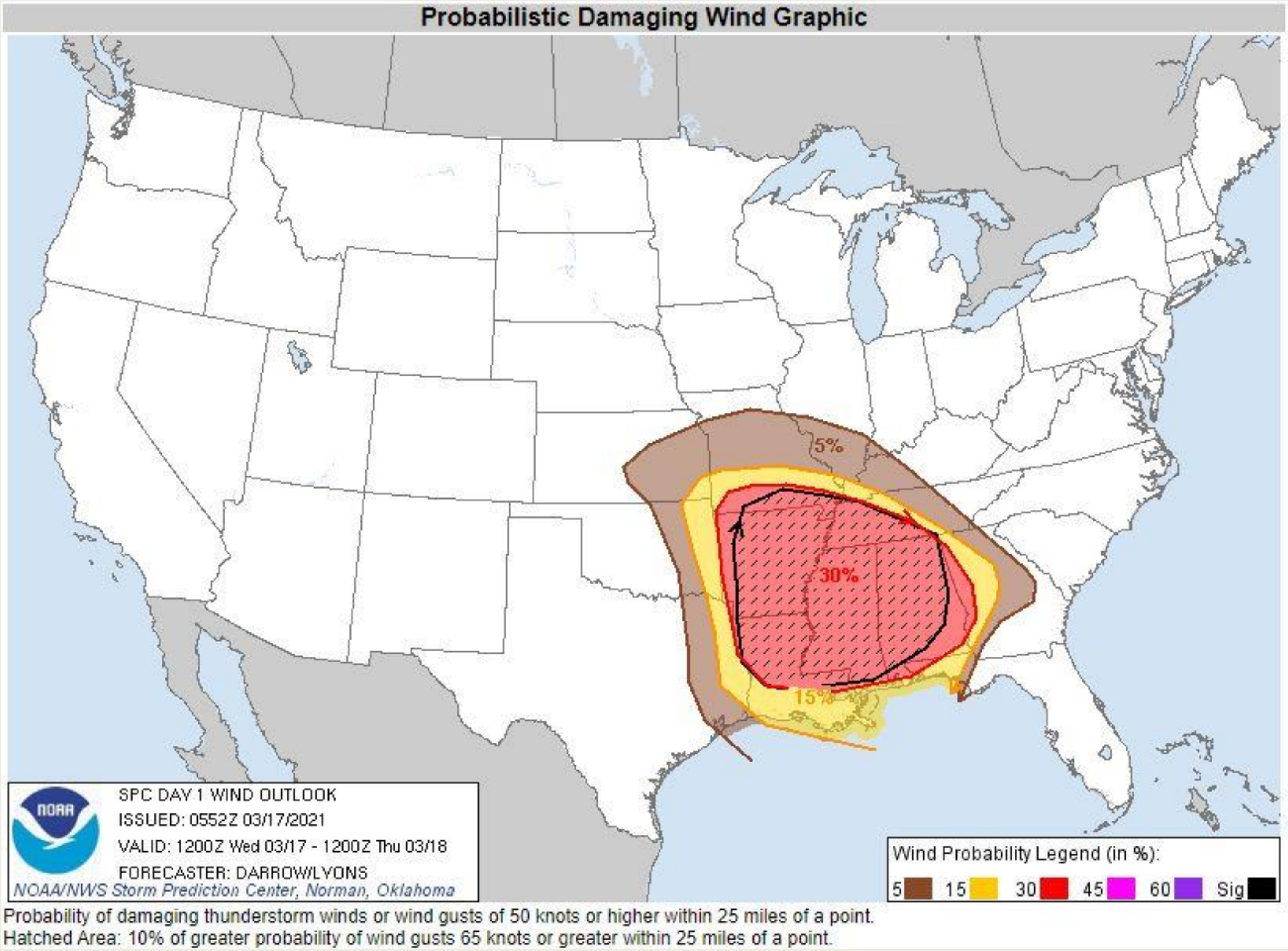
SPC Convective Outlook - example



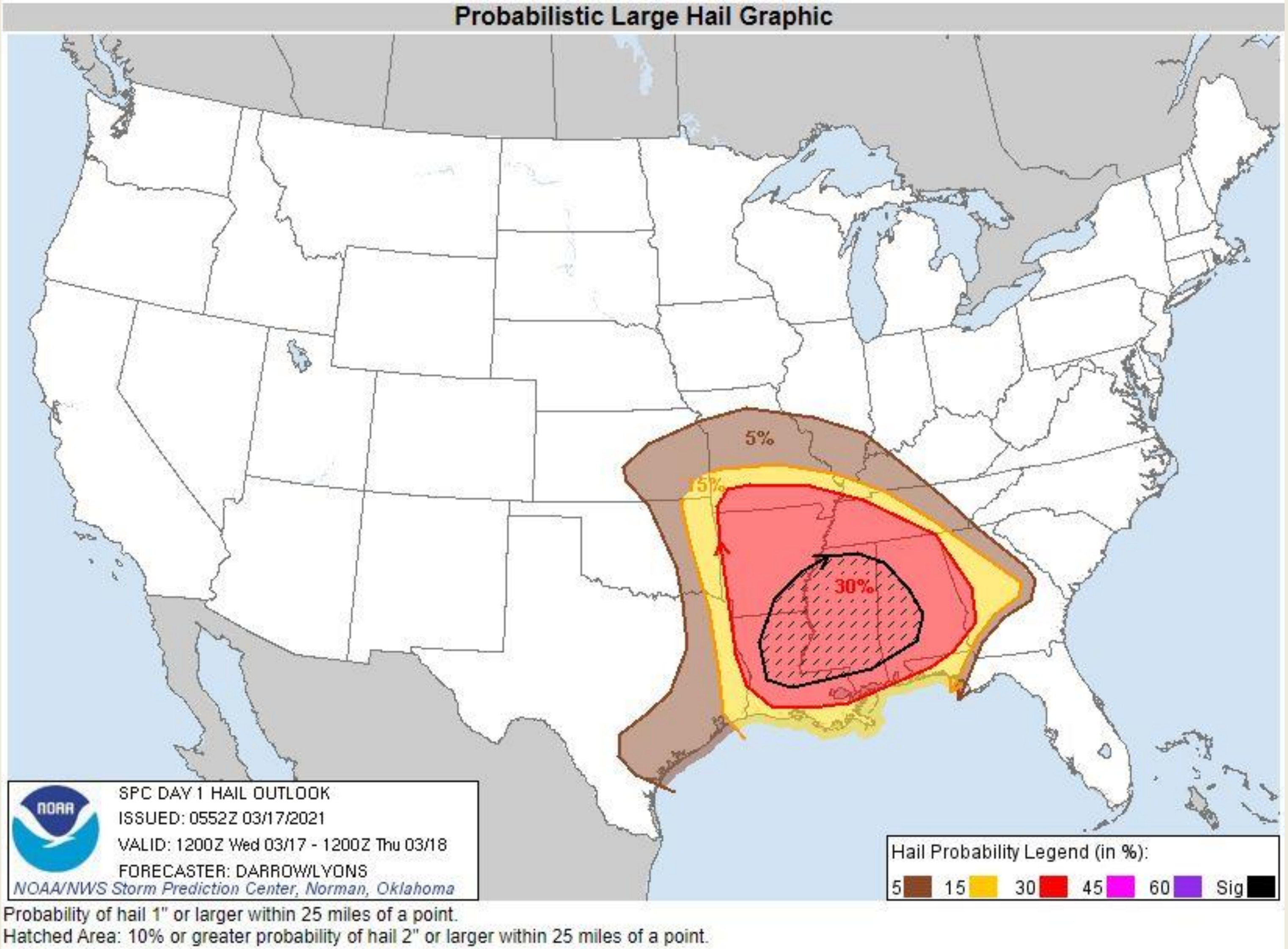
SPC Convective Outlook - example



SPC Convective Outlook - example



SPC Convective Outlook - example



URGENT - IMMEDIATE BROADCAST REQUESTED
Tornado Watch Number 36
NWS Storm Prediction Center Norman OK
645 PM CDT Wed Mar 17 2021

The NWS Storm Prediction Center has issued a

* Tornado Watch for portions of
  Alabama
  Eastern Mississippi
  Coastal Waters

* Effective this Wednesday night and Thursday morning from 645 PM
  until 300 AM CDT.

...THIS IS A PARTICULARLY DANGEROUS SITUATION...

* Primary threats include...
  Several tornadoes and a few intense tornadoes likely
  Widespread damaging winds and scattered significant gusts to 80
    mph likely
  Scattered large hail events to 1.5 inches in diameter possible

SUMMARY...A further strengthening of low/mid-level winds this evening will support a combination of semi-discrete supercells as well as organizing fast-moving line segments across much of eastern Mississippi into Alabama. Tornadoes, including a few strong, aside from damaging winds will be the most prevalent hazards.

The tornado watch area is approximately along and 100 statute miles north and south of a line from 15 miles northwest of Pine Belt MS to 35 miles southeast of Anniston AL. For a complete depiction of the watch see the associated watch outline update (WOUS64 KWNS WOU6).

PRECAUTIONARY/PREPAREDNESS ACTIONS...

REMEMBER...A Tornado Watch means conditions are favorable for tornadoes and severe thunderstorms in and close to the watch area. Persons in these areas should be on the lookout for threatening weather conditions and listen for later statements and possible warnings.

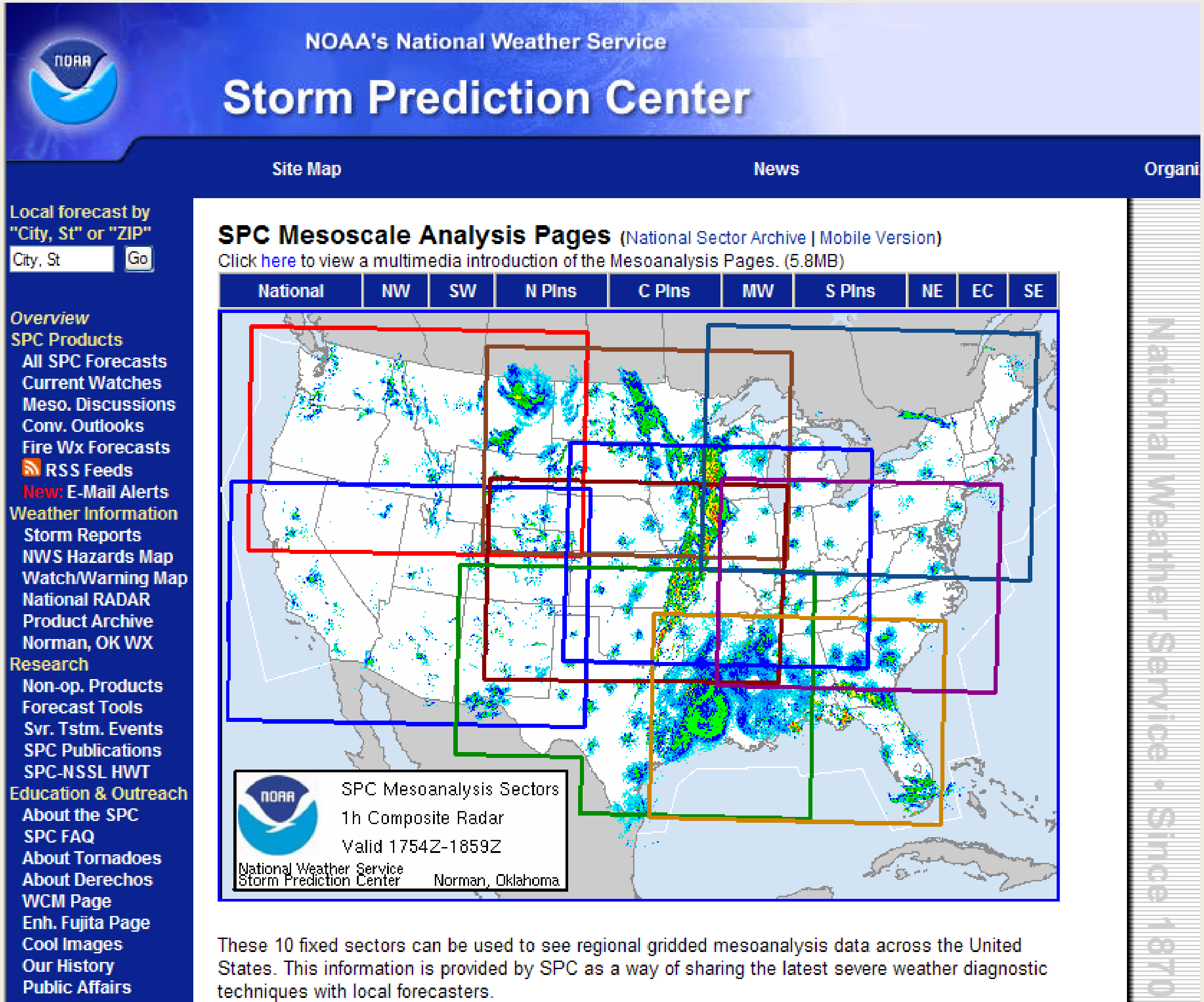
&&

OTHER WATCH INFORMATION...CONTINUE...WW 29...WW 31...WW 32...WW 33...WW 34...WW 35...

AVIATION...Tornadoes and a few severe thunderstorms with hail surface and aloft to 1.5 inches. Extreme turbulence and surface wind gusts to 70 knots. A few cumulonimbi with maximum tops to 500. Mean storm motion vector 24040.

...Guyer

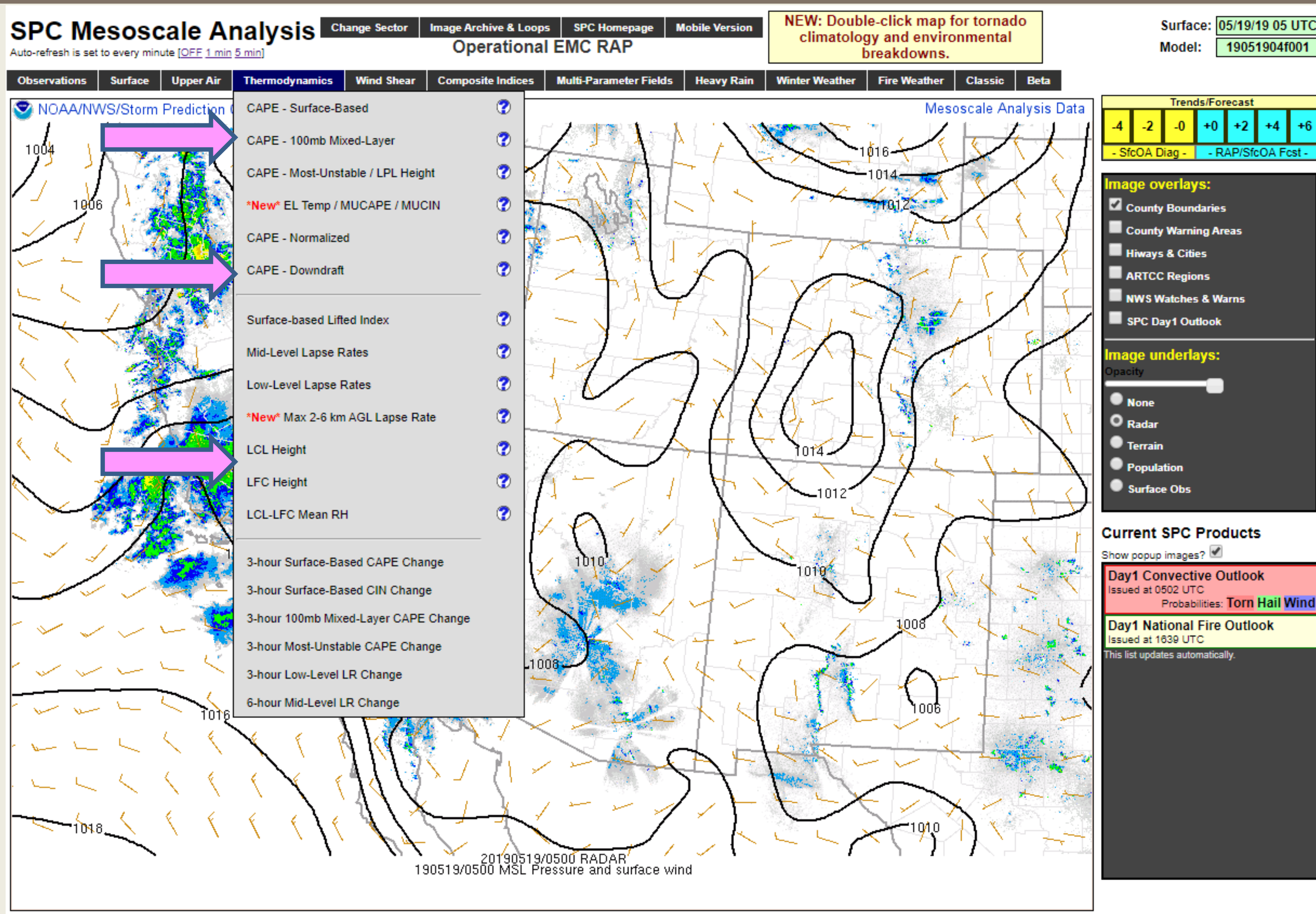
Main Mesoanalysis Page



Access from the "Forecast Tools" or "Mesoanalysis" links on SPC main page

Select subsector of interest, main analysis screen will appear

Drop-Down Menu: Thermo



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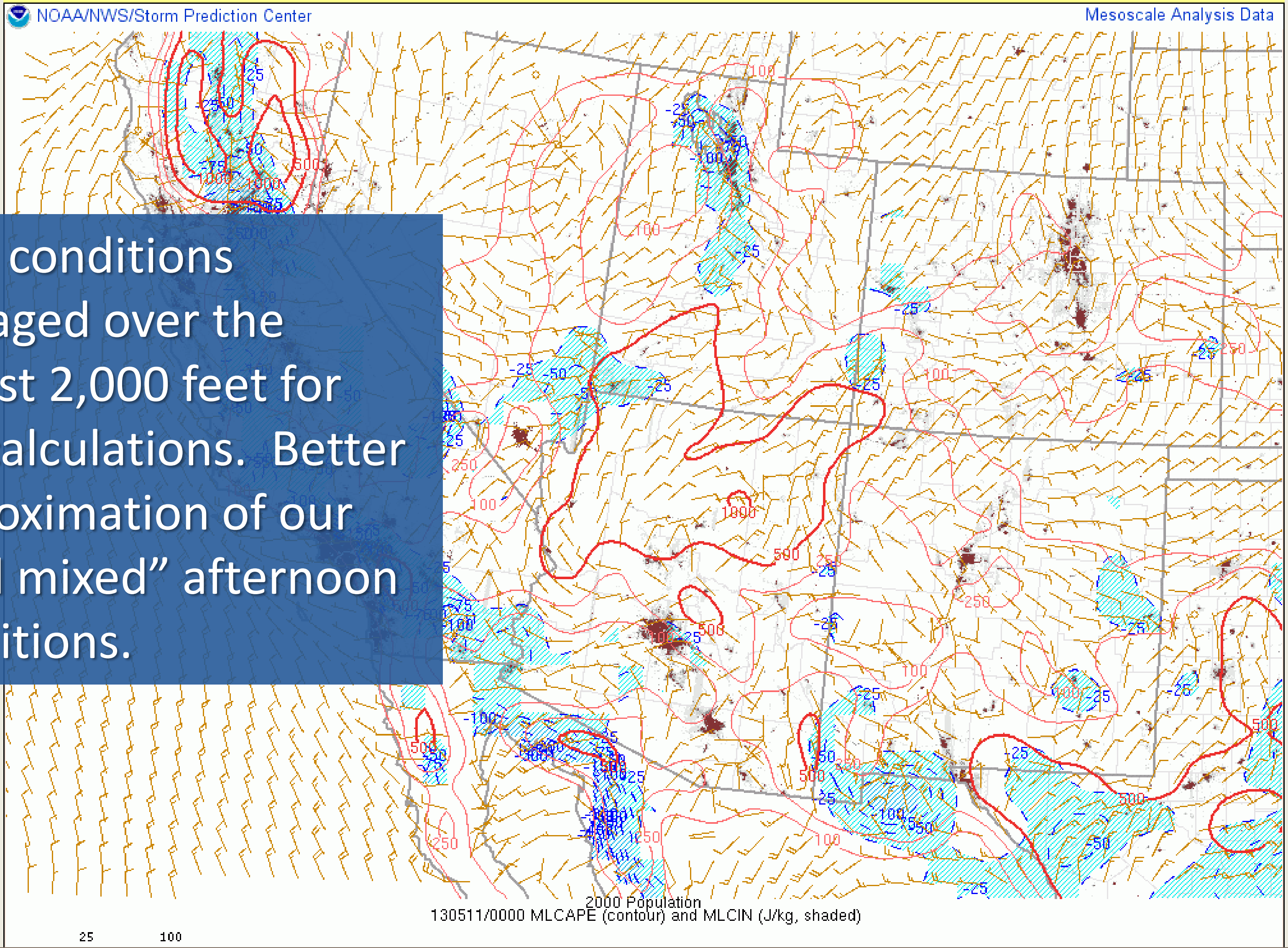
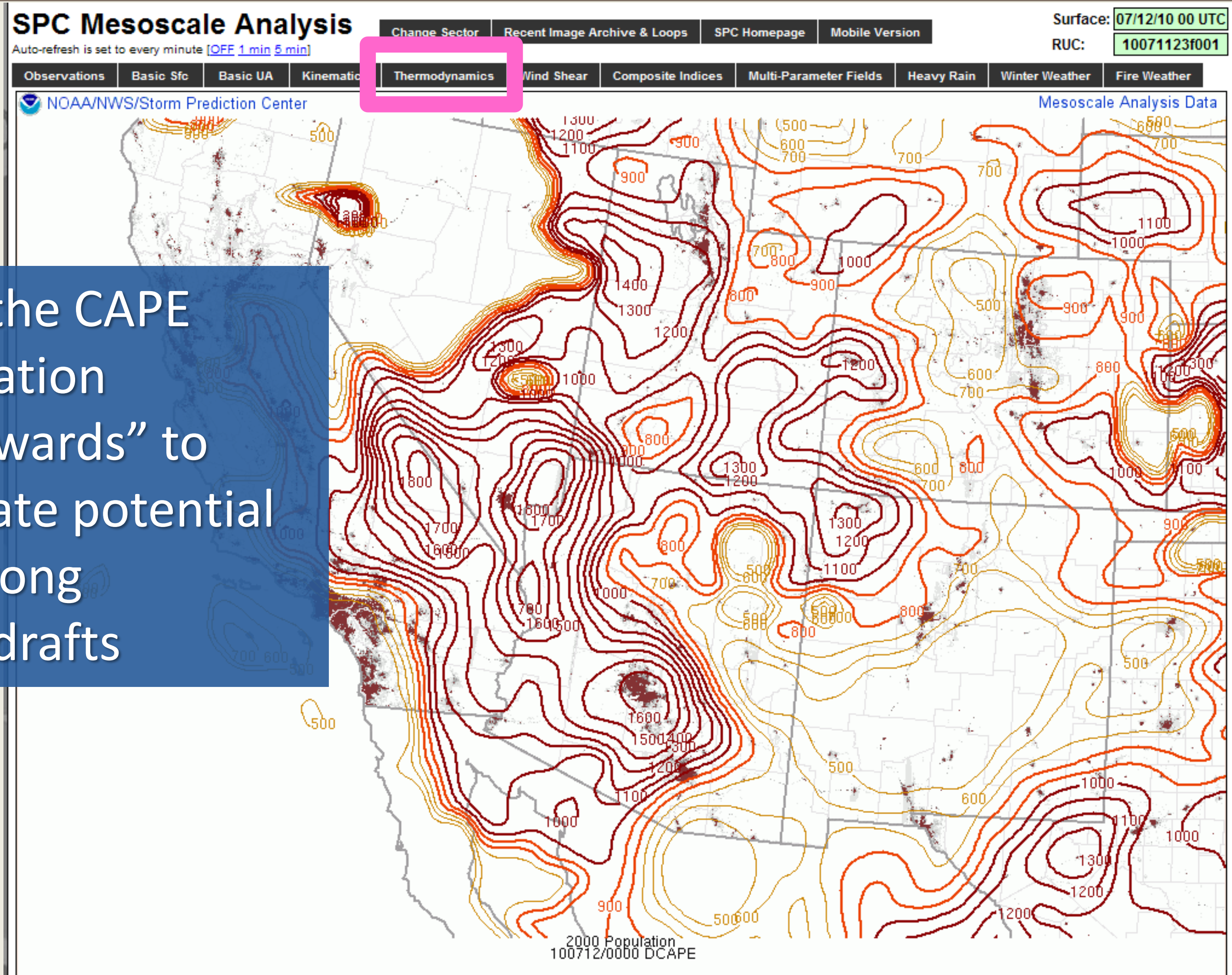
Mixed-Layer CAPE



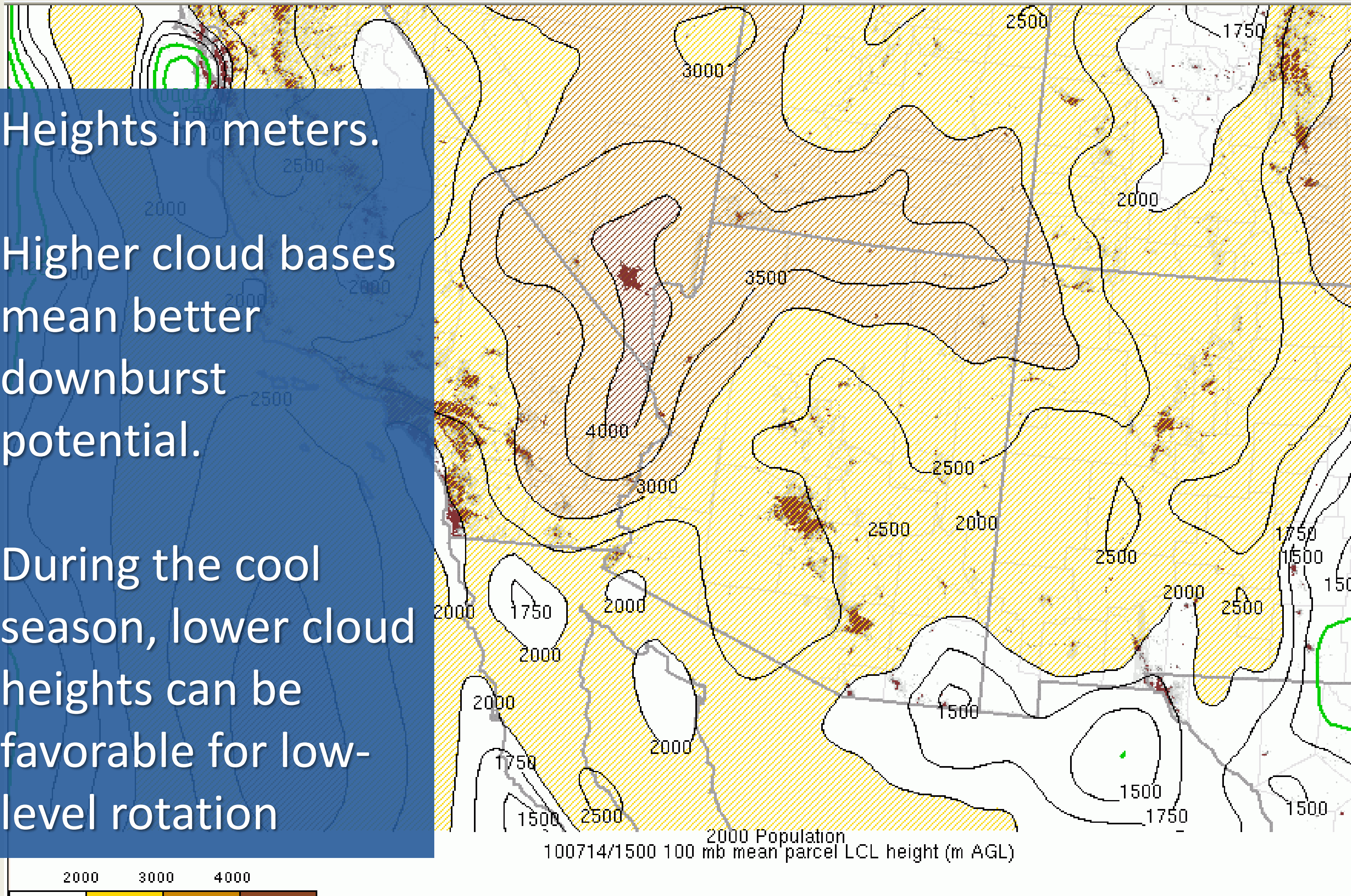
Uses conditions averaged over the lowest 2,000 feet for the calculations. Better approximation of our "well mixed" afternoon conditions.

Downdraft CAPE



Runs the CAPE calculation “backwards” to estimate potential for strong downdrafts

LCL (Cloud Height)

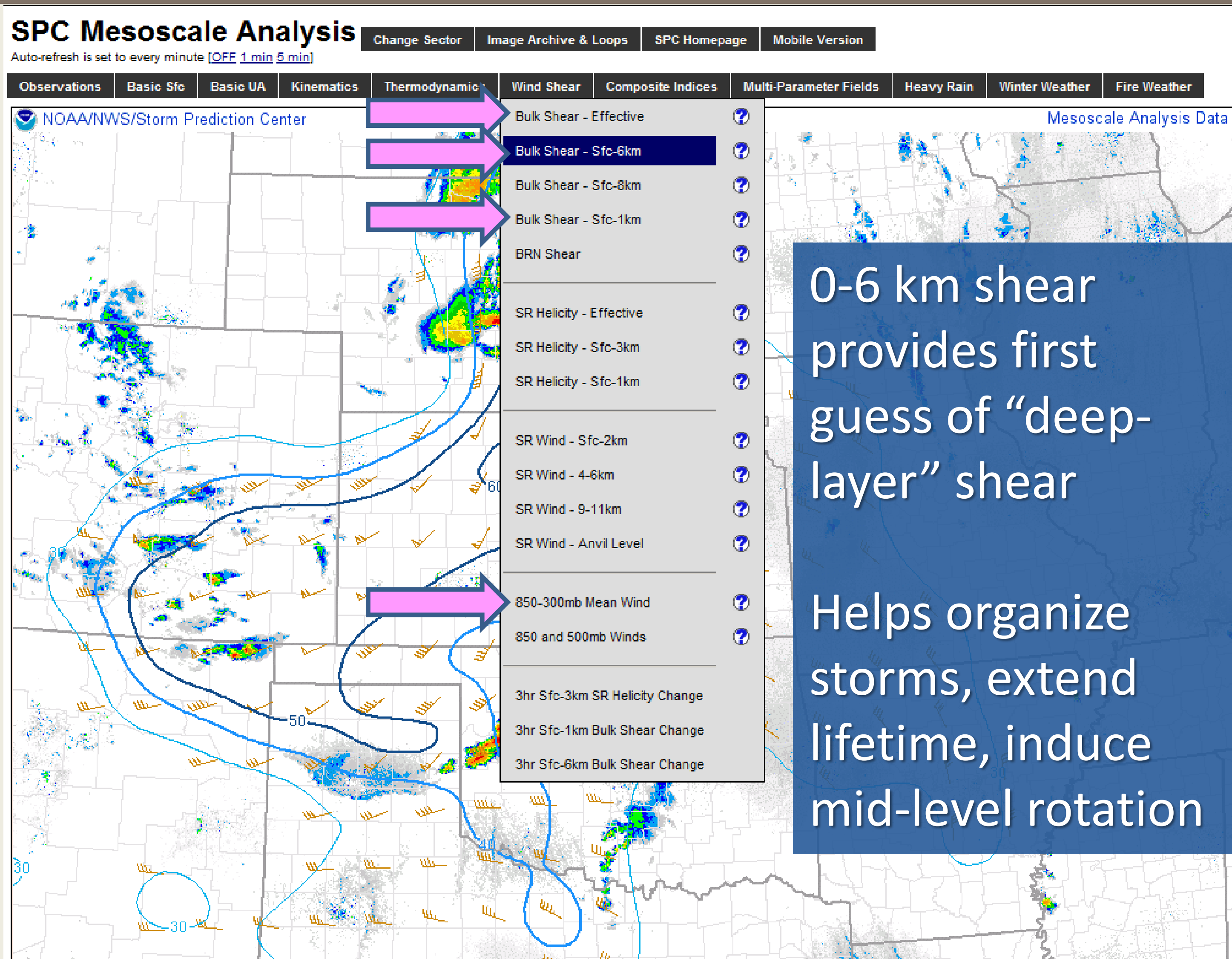


Heights in meters.

Higher cloud bases mean better downburst potential.

During the cool season, lower cloud heights can be favorable for low-level rotation

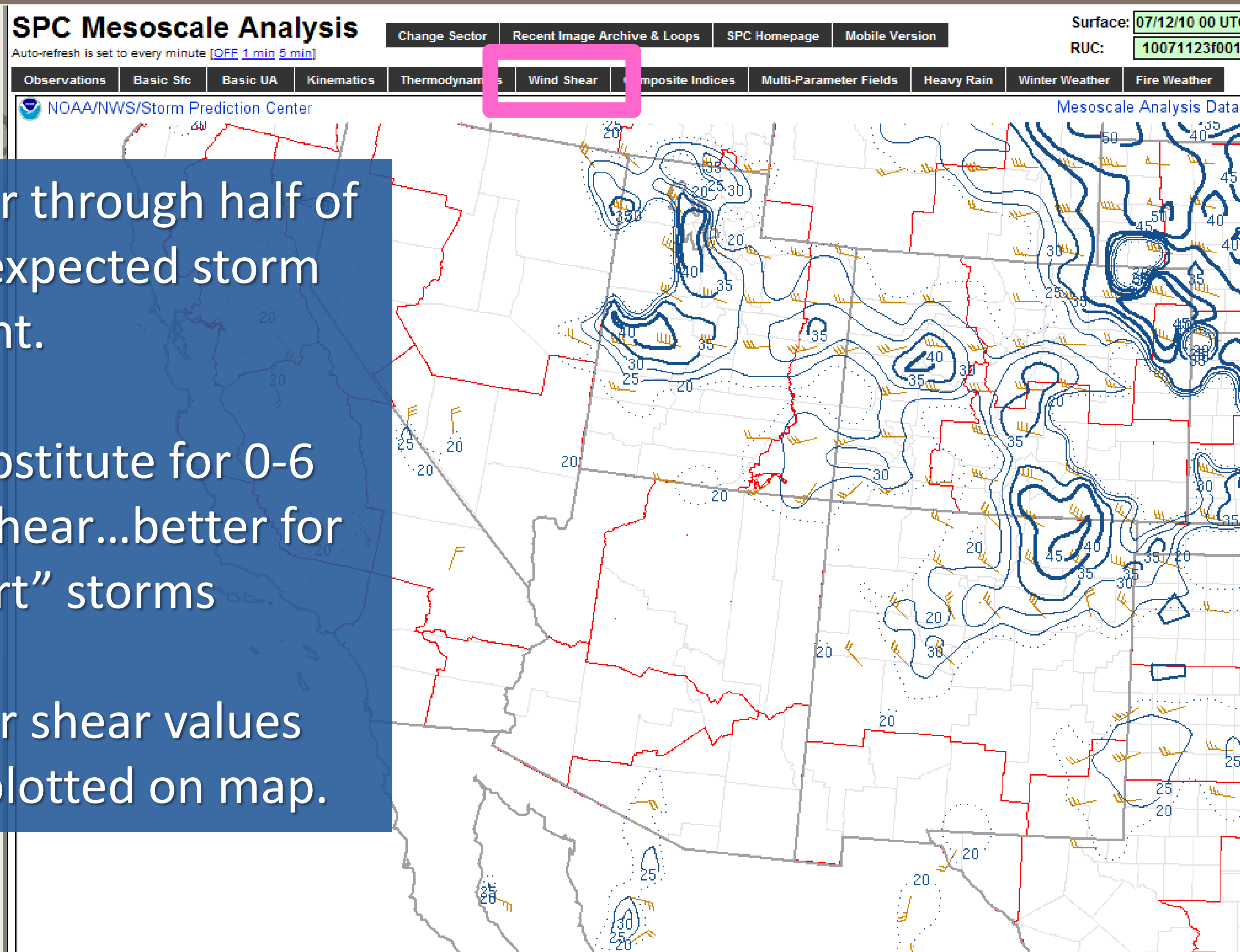
Wind Shear



0-6 km shear provides first guess of “deep-layer” shear

Helps organize storms, extend lifetime, induce mid-level rotation

"Effective" Wind Shear

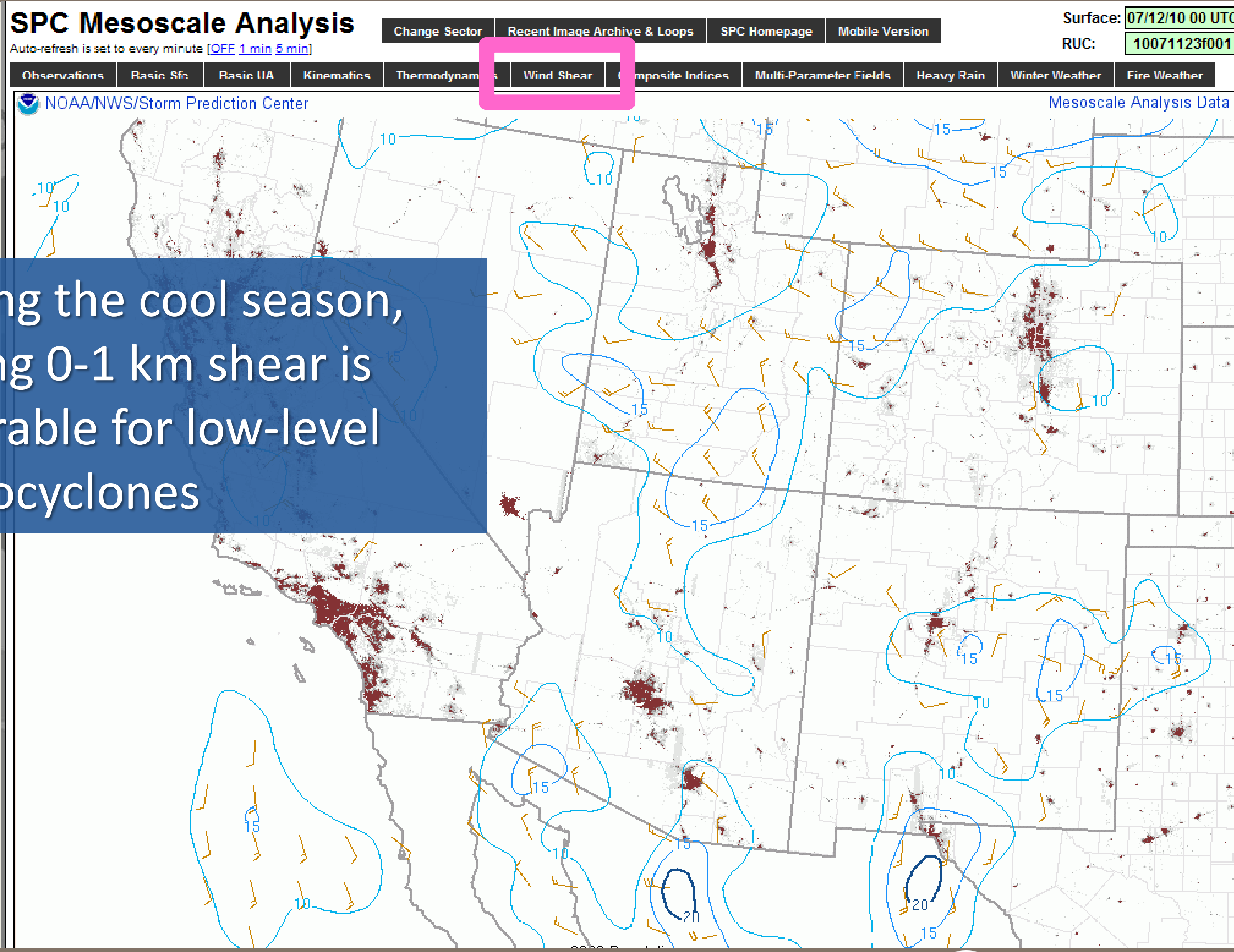


Shear through half of the expected storm height.

A substitute for 0-6 km shear…better for "short" storms

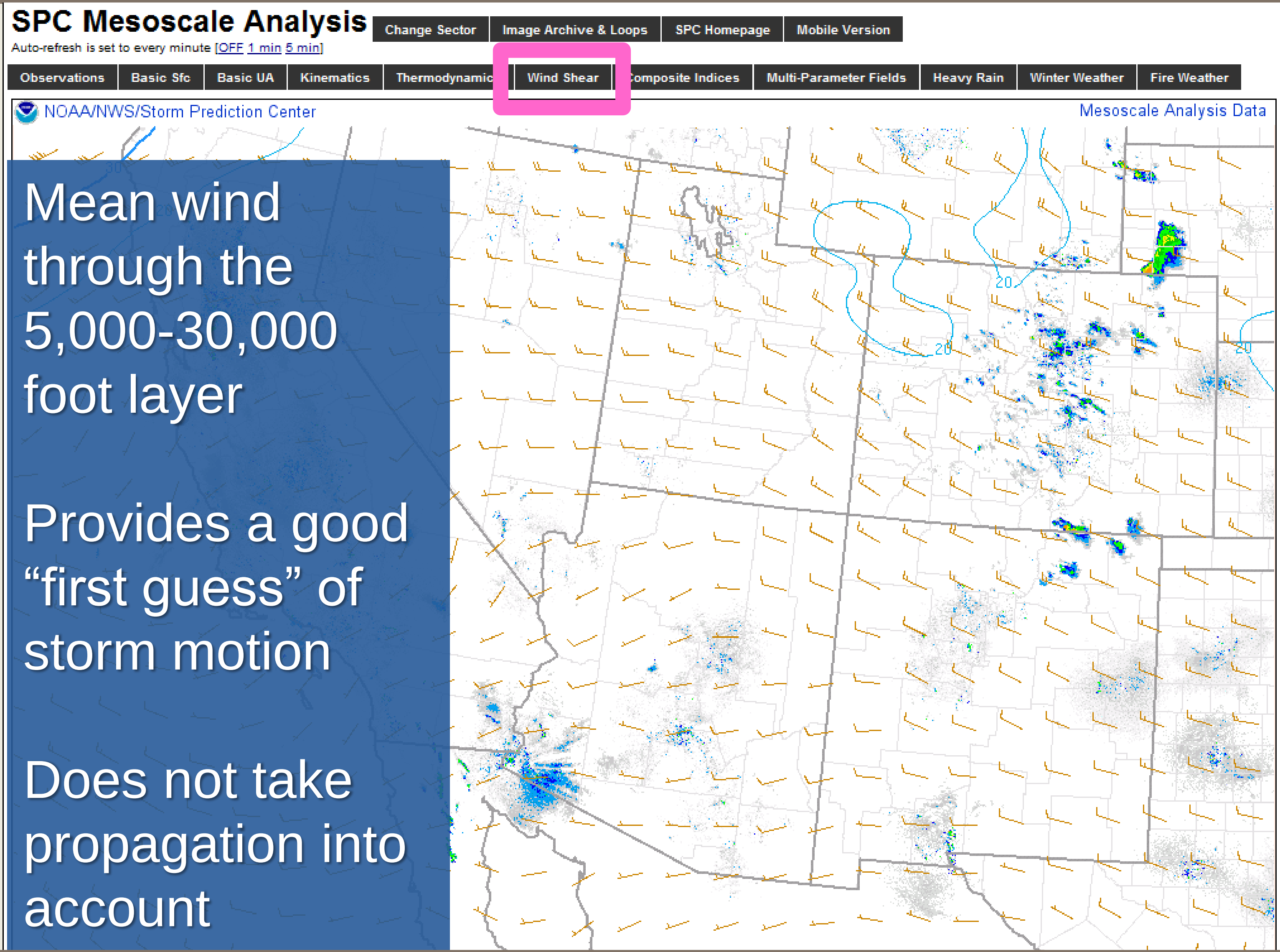
lower shear values are plotted on map.

0-1 km Wind Shear



During the cool season, strong 0-1 km shear is favorable for low-level mesocyclones

850-300 mb Mean Wind



Mean wind through the 5,000-30,000 foot layer

Provides a good "first guess" of storm motion

Does not take propagation into account

Key Parameter Guidelines

- **CAPE:** At least 250 J/kg; 1000+ for significant updrafts
- **CIN:** -100 J/kg or weaker for breakable cap
- **Downdraft CAPE:** 1000 J/kg or stronger for downbursts
- **Deep layer shear (effective or 6 km):** 25 knots or greater for organized storms, 35 kts or greater for mid-level rotation (mesocyclones)
- **0-1 km shear (cool season or transition):** 20 knots or greater for low-level rotation (mesocyclones)
- **LCL height (cool season/transition):** < 4000 ft (1200 m) is favorable to hinder the occurrence of overly strong downdrafts that would break up low level circulations.

Program Outline

Part I

- Organized Storm Ingredients
- Storm Classification
- Tornadoes & Land Spouts
- The Monsoon

Part II

- Mesoanalysis Tools
- Radar Analysis
- Case Studies

What is Radar?

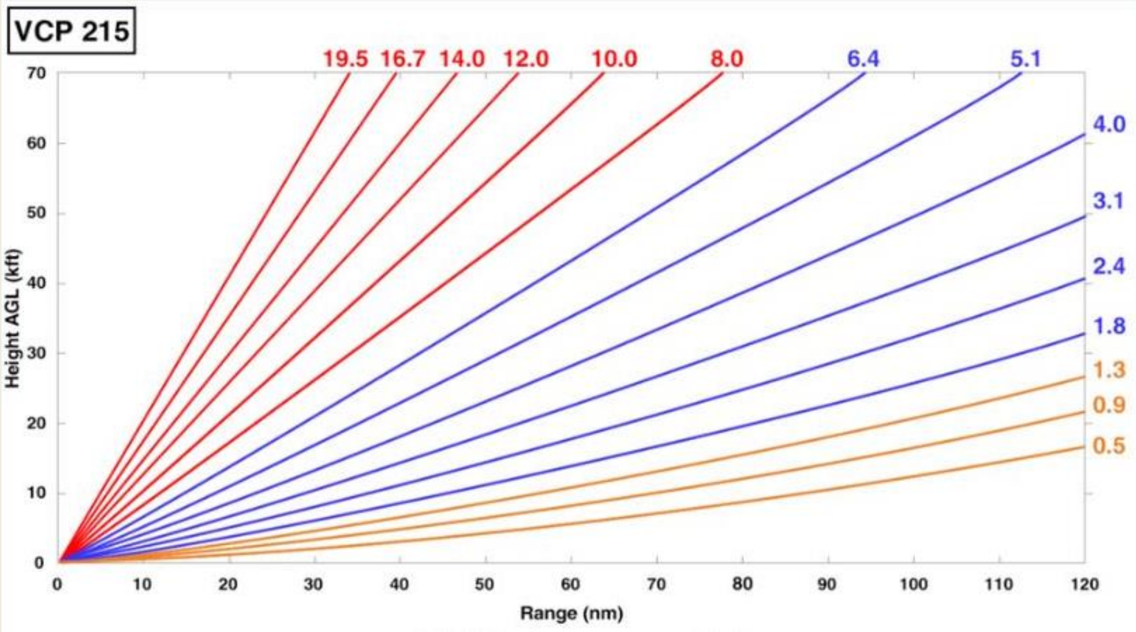
- RADAR is **RA**dio **D**etection **A**nd **R**anging
- In use since World War II
- Most efficient means of detecting precipitation
- Current NWS network radar is the Weather Surveillance Radar (WSR) 88D

How Does Radar Work?

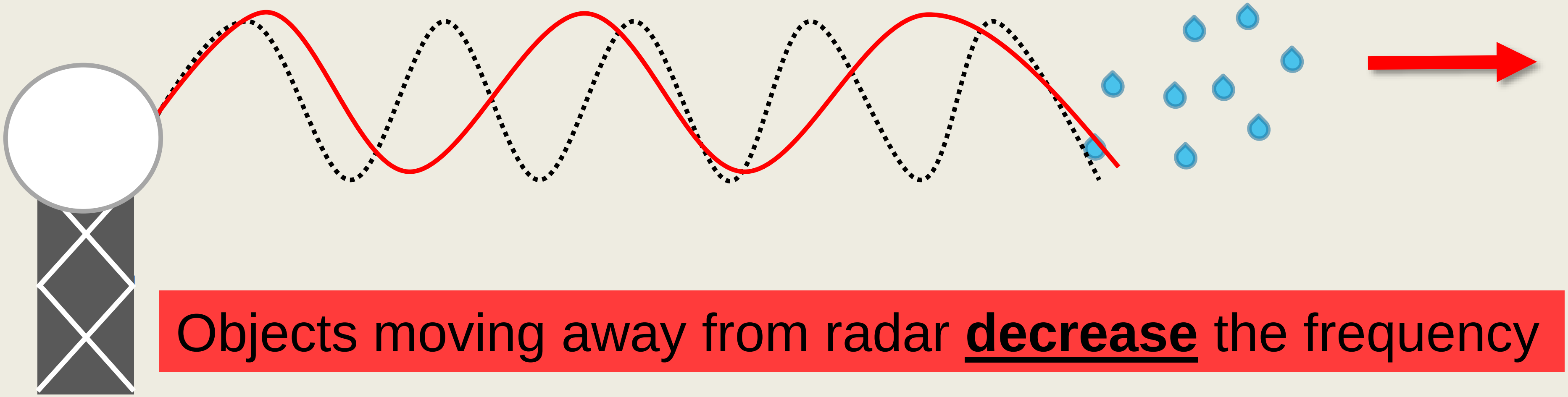
- Transmitter sends short burst of radio waves
- Waves travel at the speed of light
- When waves strike a target, a small portion is reflected back to the antenna (Reflectivity)
- System keeps track of direction/distance, plots areas of Reflectivity ("echoes")
- System repeats process about 1,000 times a second!

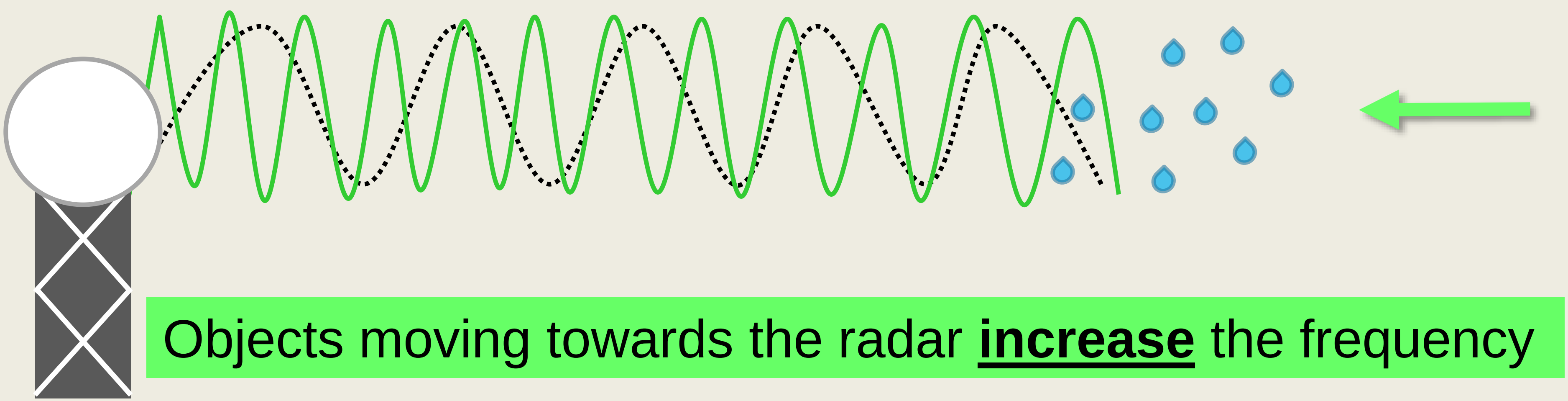
WSR-88D Overview

- Doppler radar with supporting computer algorithms
- Uses "volume scans" to sample atmosphere
- Base reflectivity and velocity for each elev.
- "Derived products" generated for each volume scan



WSR-88D Velocity





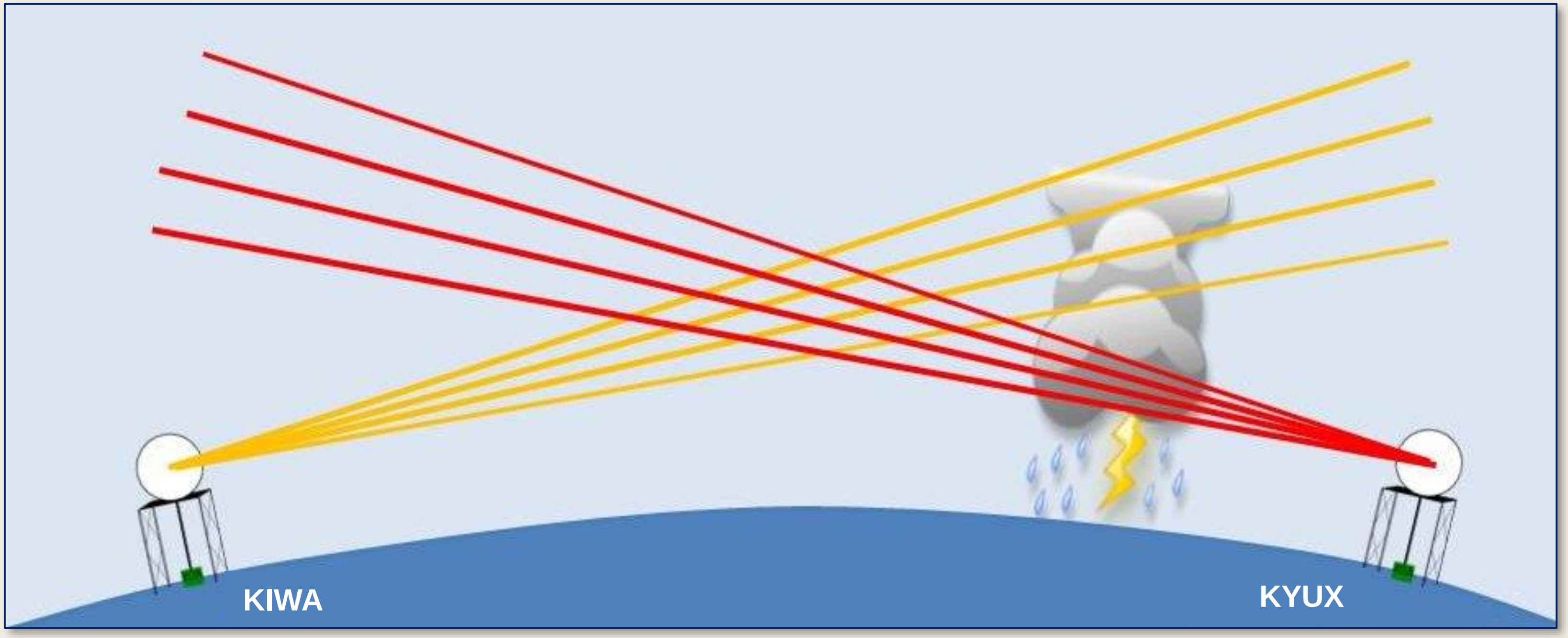
RADAR Limitations

Beam Spreading

- Width of beam depends on distance from the radar
- Expands ~1,000 feet every 10 miles
- At 60 miles out, beam is 6,000 feet wide
- Affects resolution capability of radar
- Small features easily seen at close range become obscured at long distances

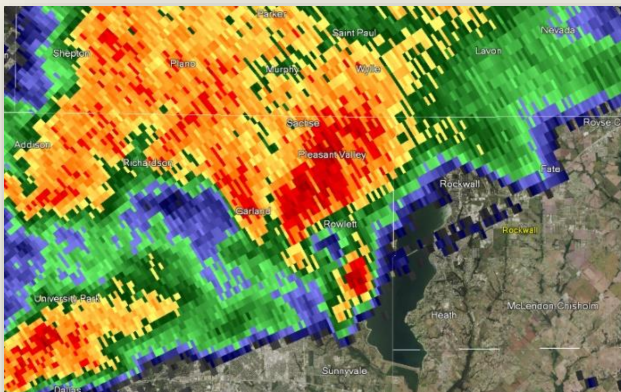
RADAR Limitations

Curvature



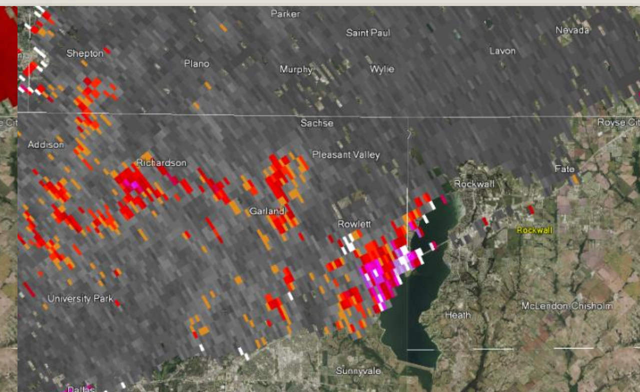
Due to the curvature of the earth, the radar beam will increase in height relative to the ground – meaning only higher and higher hydrometeors will be detected. At increasing distances, low objects become undetectable.

Classic Radar Products



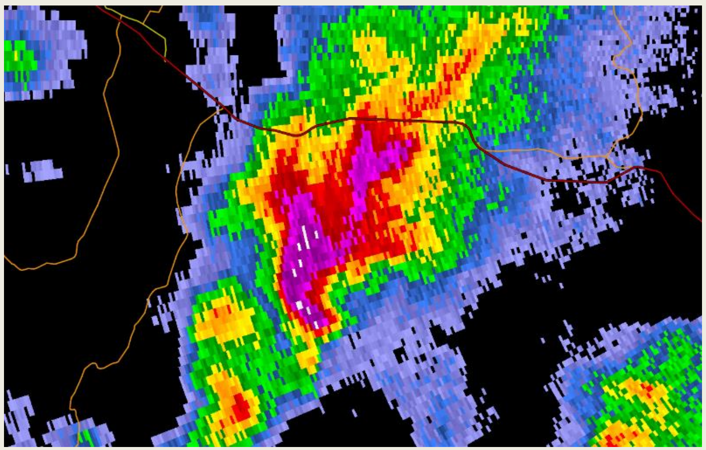
Reflectivity

Velocity



Spectrum Width

Reflectivity: What & How Much



- Measures returned power back to the radar from a target
- Intensity of meteorological target is inferred from the power return
- Larger particles return more energy than smaller ones
- Units of dBZ
- Scale from -35 to +85 dBZ

Extremely Heavy or hail

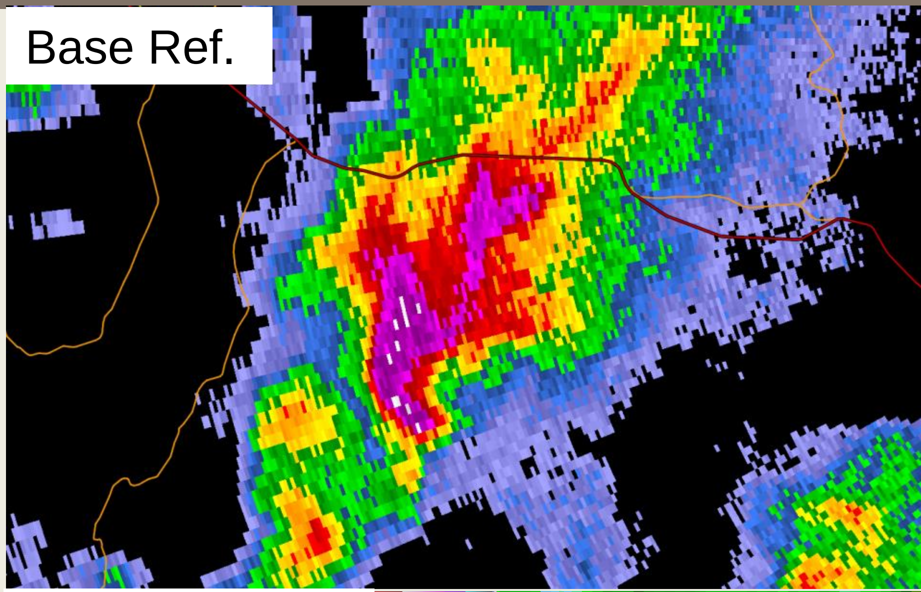
Heavy

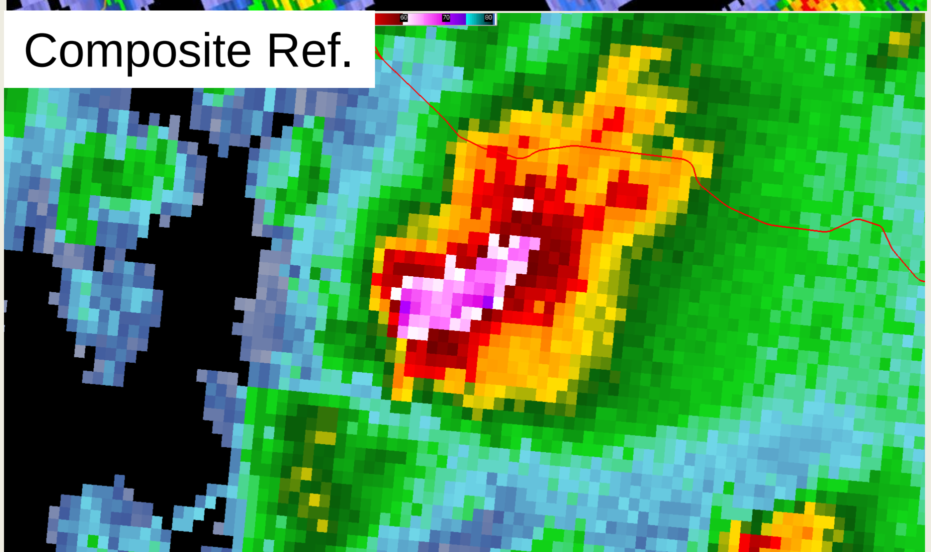
Moderate

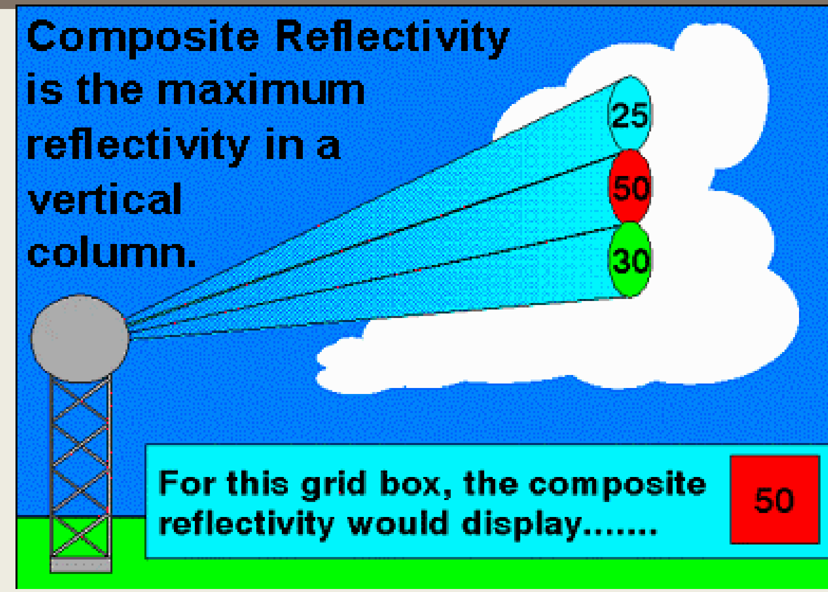
Light

Extremely Light

Base vs. Composite Reflectivity





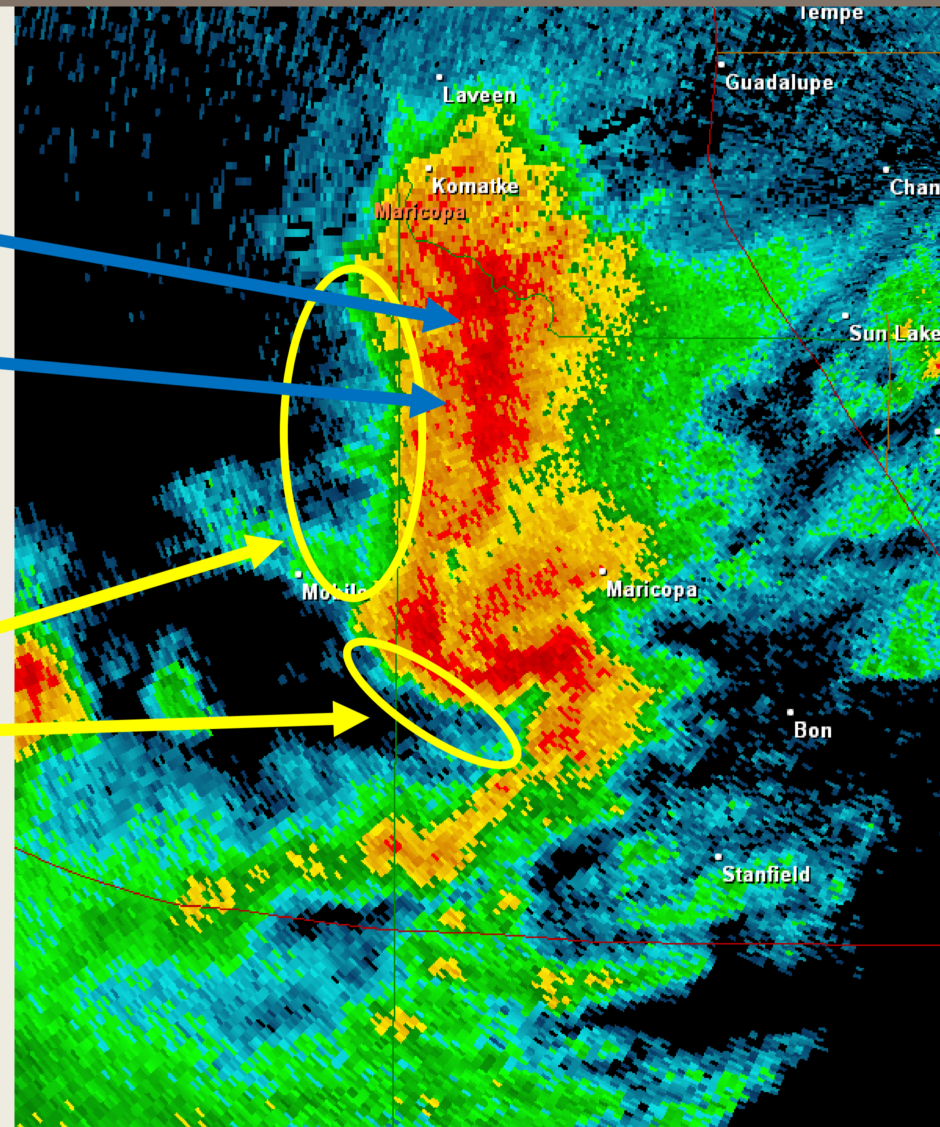


- BR is useful to identify details. Notice the hook echo not seen in Composite Reflectivity!
- CR is useful for large area surveillance – especially when storms are high based.

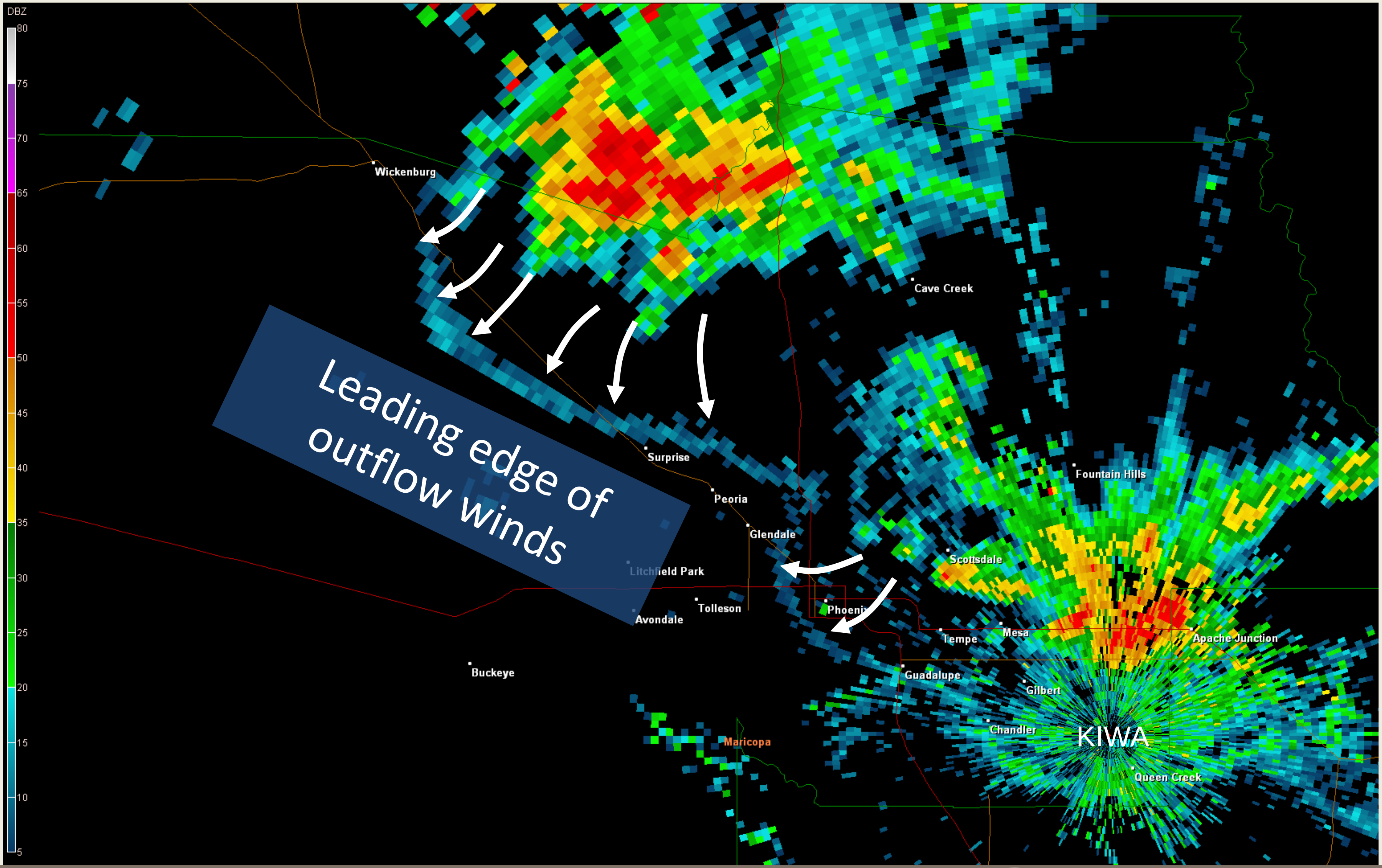
Radar Applications: Reflectivity

High reflectivity = very heavy rain & possible hail

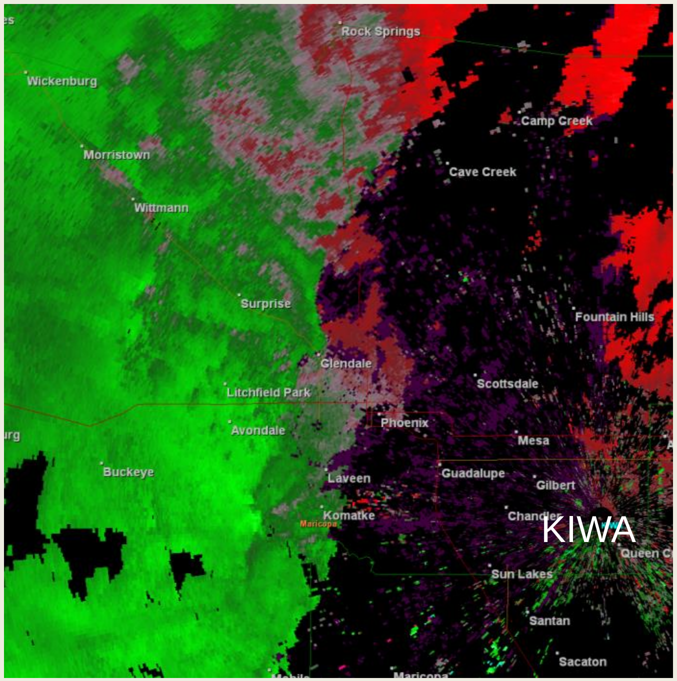
Tight reflectivity gradient = updraft/downdraft interface



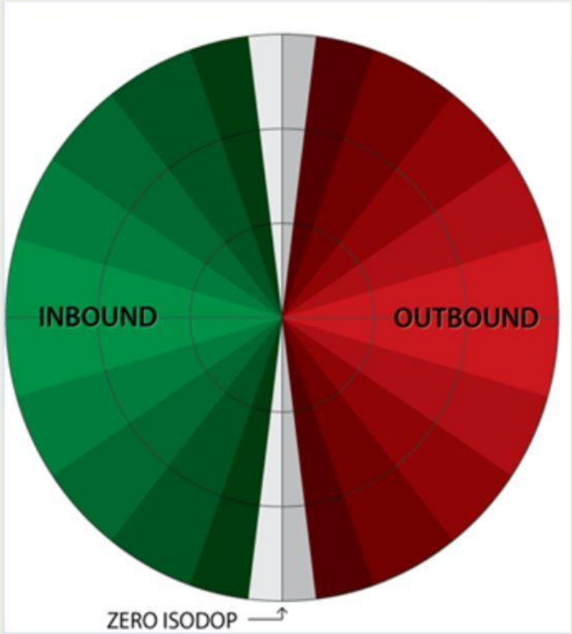
Radar Applications: Reflectivity



Velocity: Which Direction & How Fast



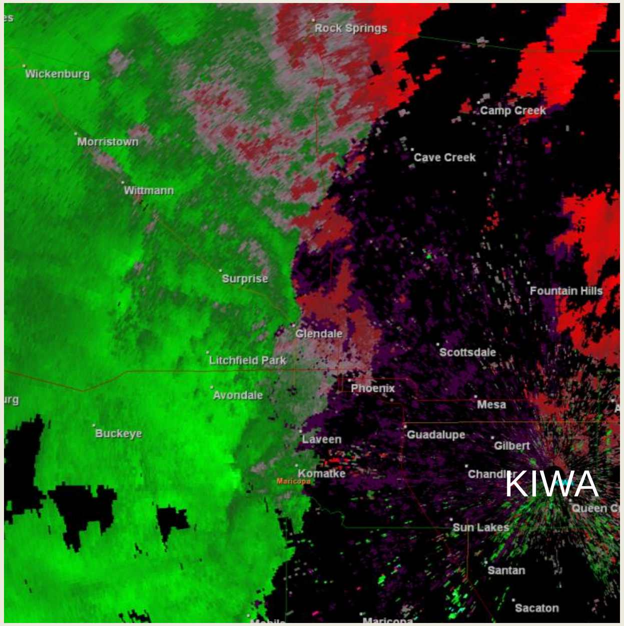
- **Radial velocity** is the <u>component of the true velocity</u> that is moving parallel to the beam.
- When the radar beam is perpendicular to the direction of motion, <u>radial</u> velocity will be **zero**.



Base Velocity vs. Storm Relative Velocity

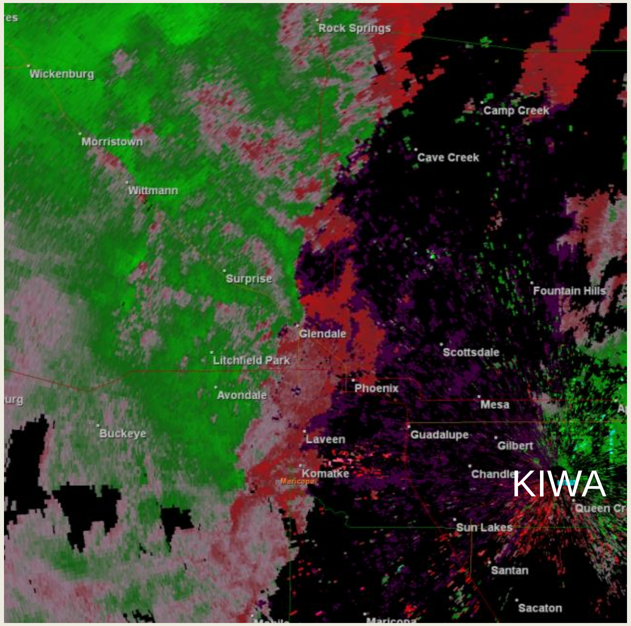
Base Velocity

- Ground relative
- **Best for estimating straight line wind speeds**
- Can estimate inflow if a storm is close to the radar

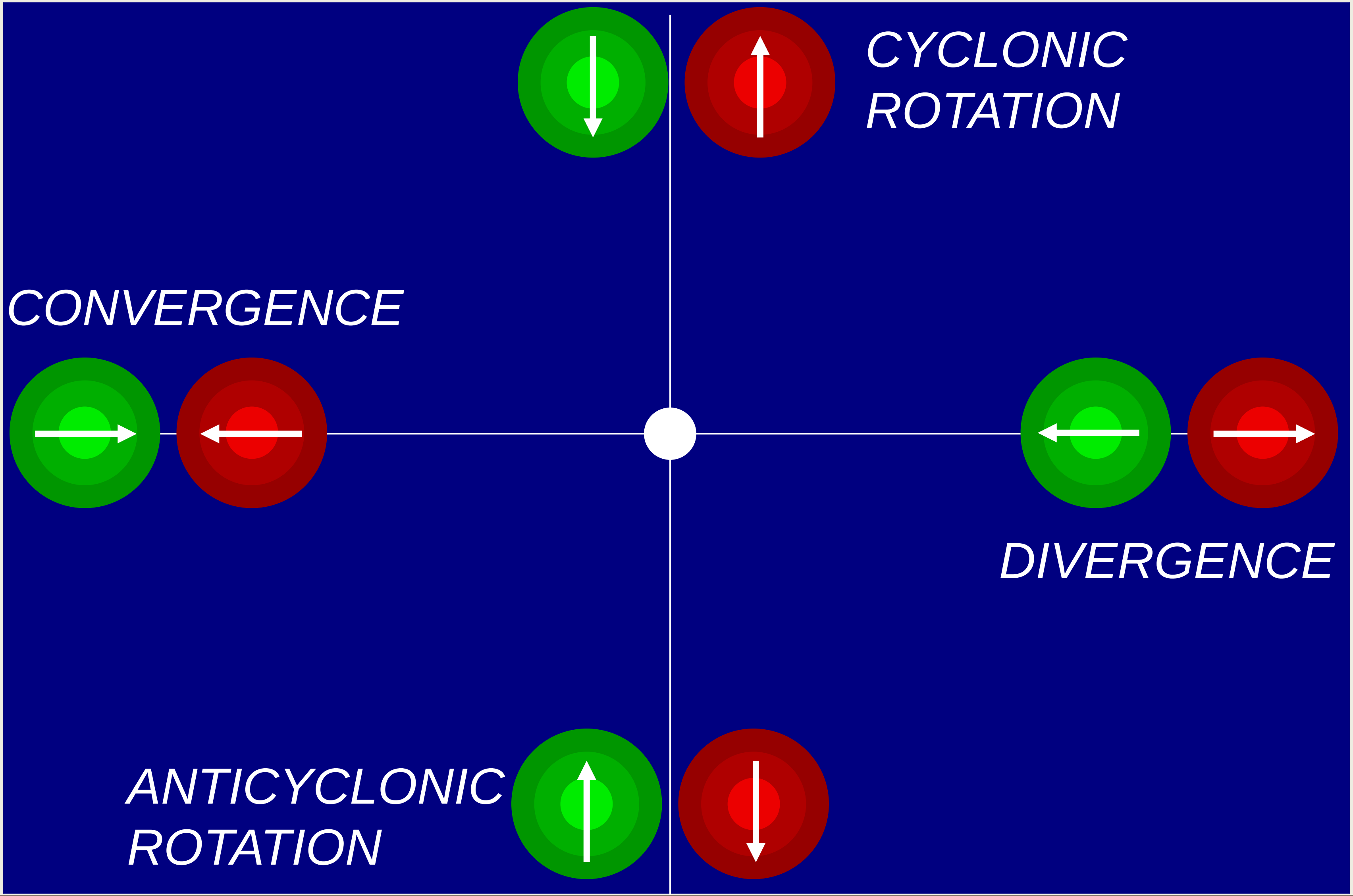


Storm Relative Velocity

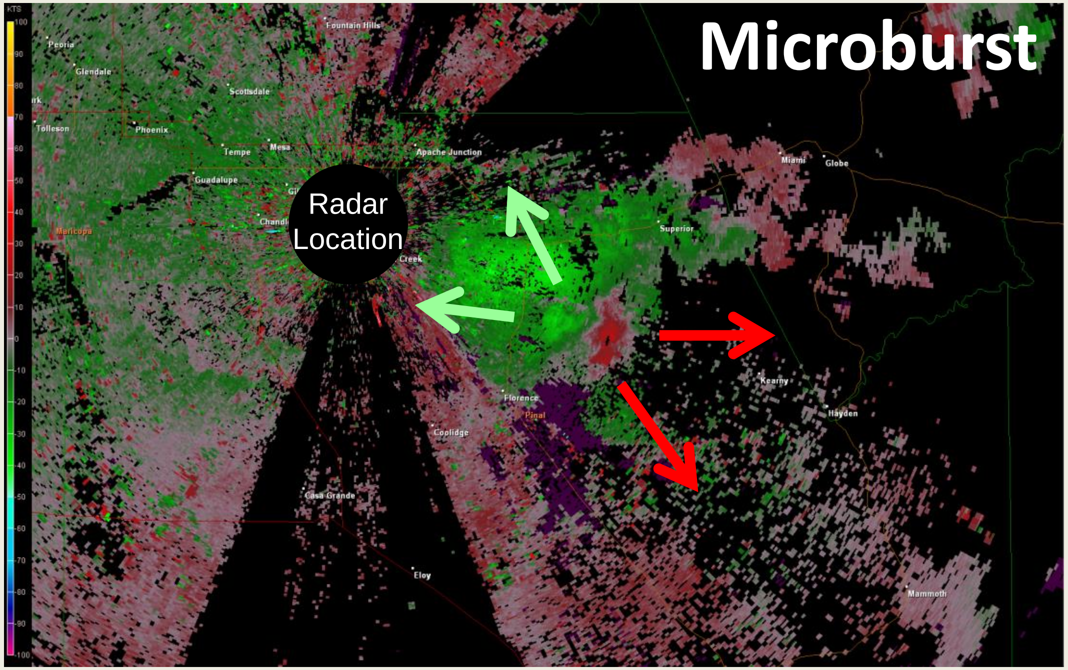
- Storm motion subtracted out
- **Best for identifying rotation**
- Good for convergence/divergence

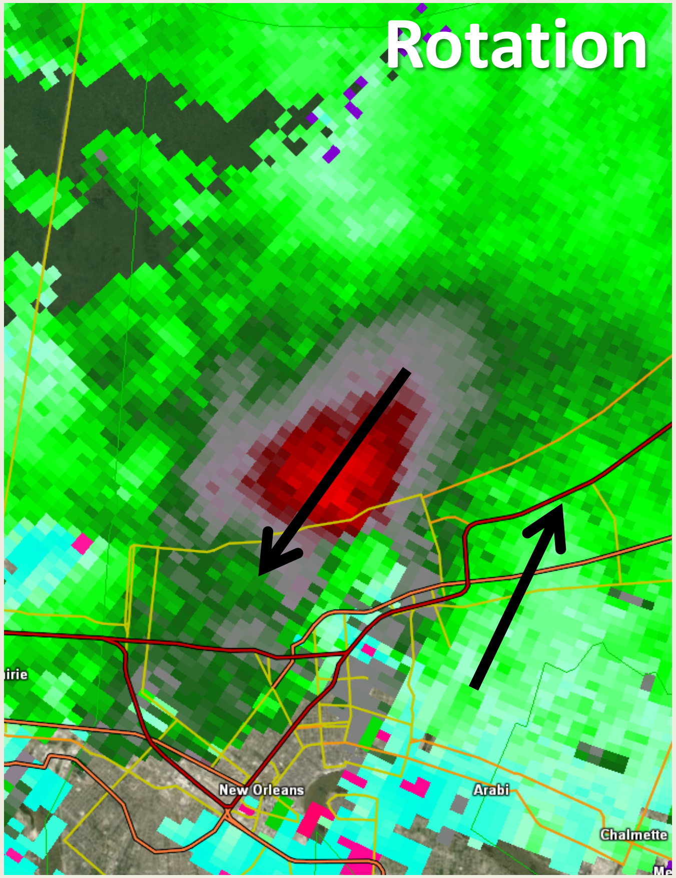


Radial Velocity Signatures



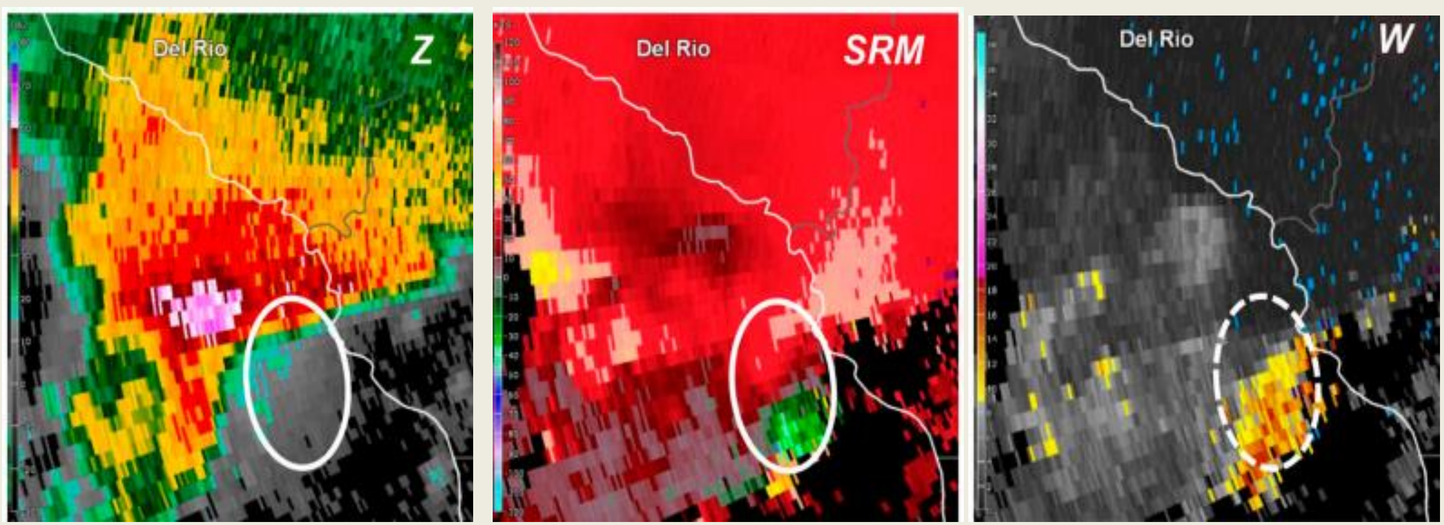
Velocity Signatures





Spectrum Width: Variability of Motion

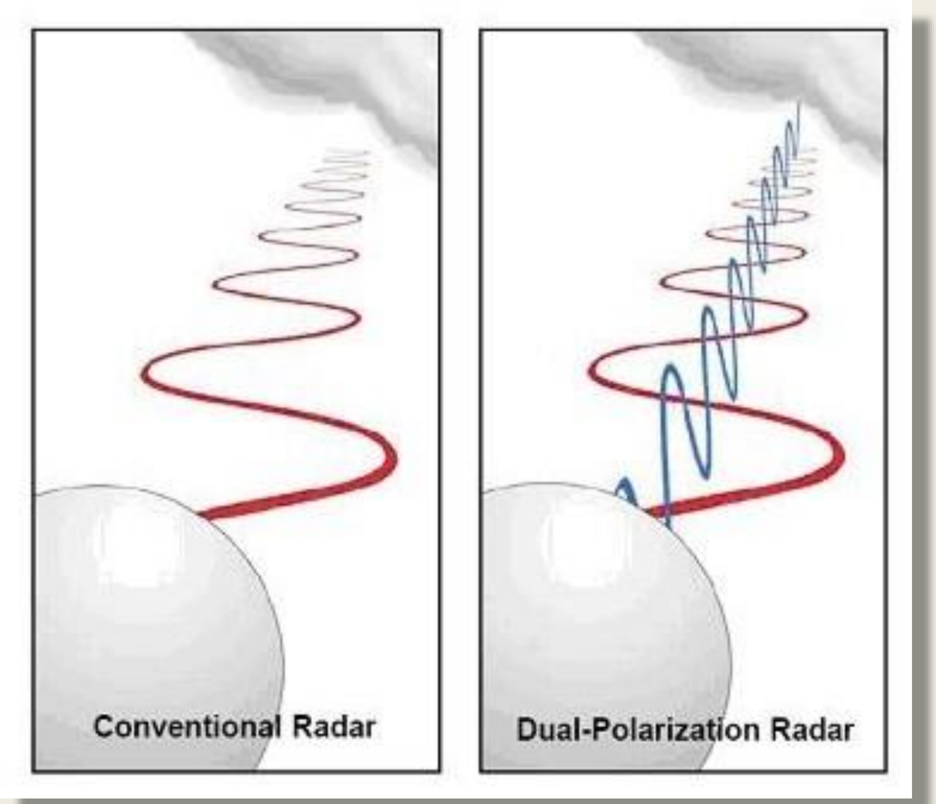
- A measure of how much Doppler velocity varies within a radar bin
- Higher spectrum width means more variation in velocity
- High spectrum width can indicate turbulent motion, but can also highlight data quality issues



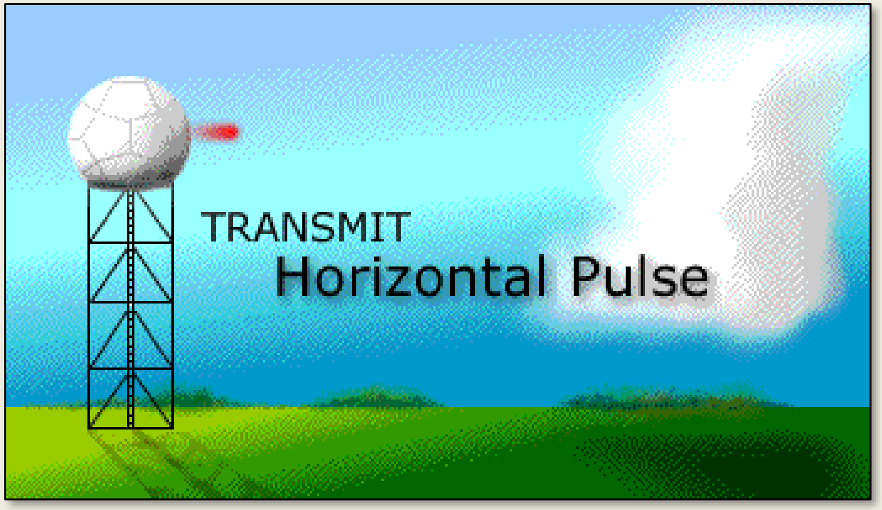
(adapted from Nai et al., 2020)

Dual Polarization

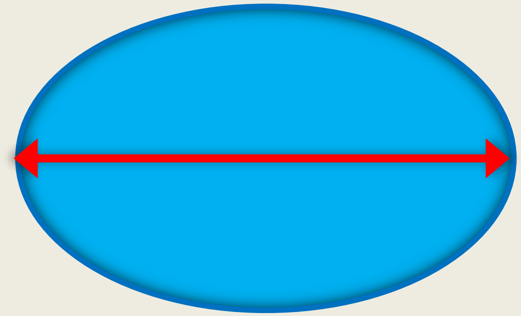
- Conventional radar radio waves “vibrate” in the horizontal
  - Best for detecting “flat” raindrops
- Dual polarization waves “vibrate” in the vertical and the horizontal
  - Detects more details associated with precipitation shape and size



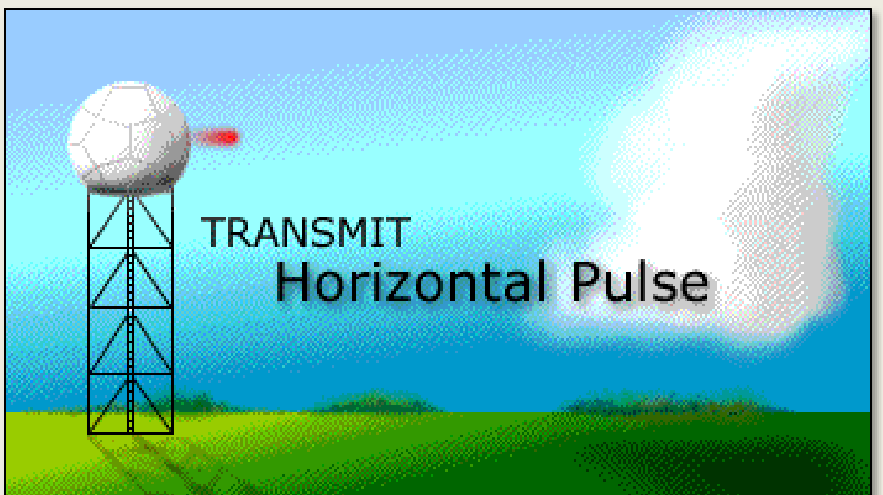
Dual Polarization

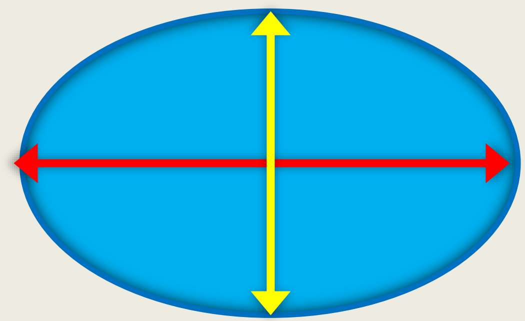


Reflected Energy → Reflectivity



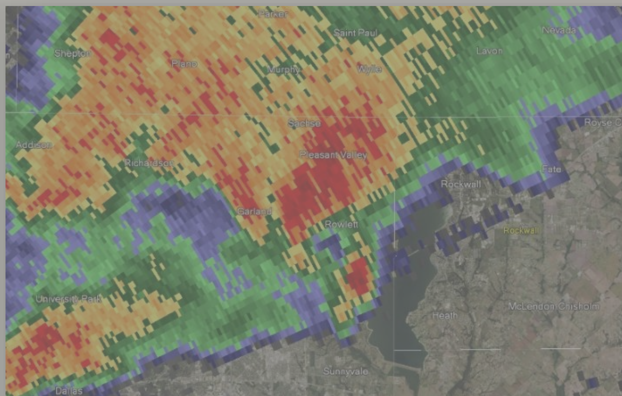
Bigger the drop, the more energy reflected, the higher the <u>reflectivity</u>.



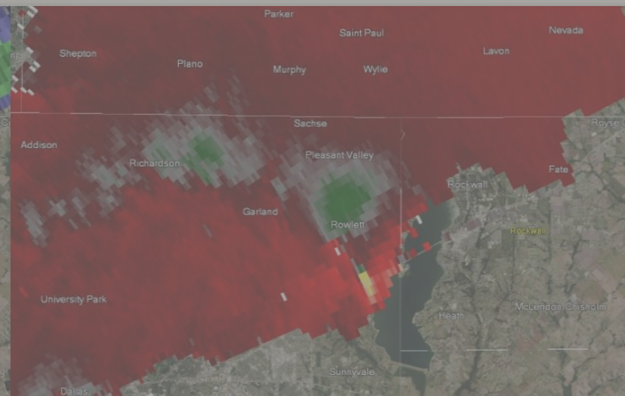


For a big drop, there is more energy reflected in the horizontal than vertical.

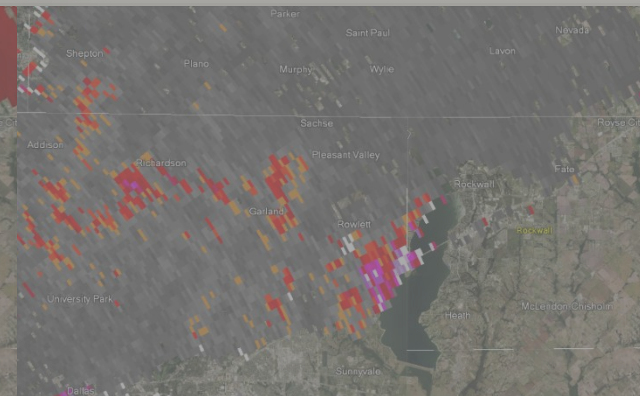
Dual-Pol Radar Products



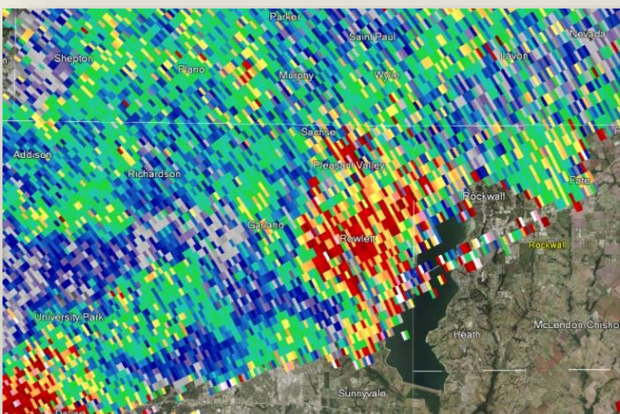
Reflectivity



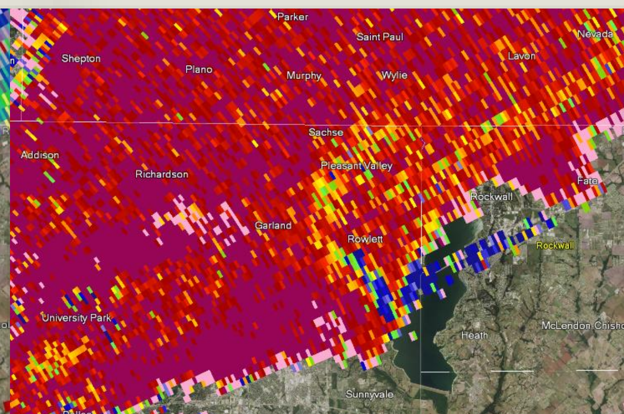
Velocity



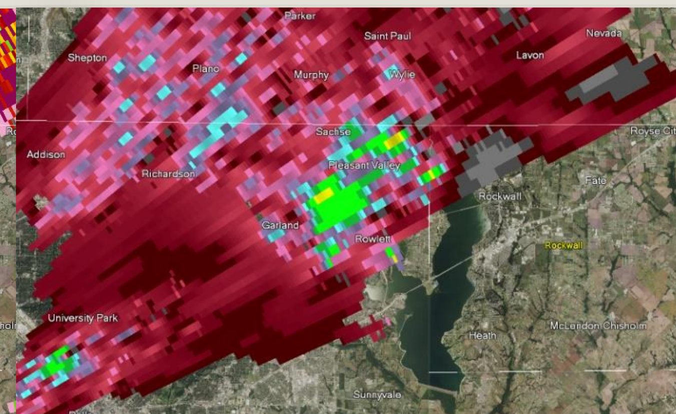
Spectrum Width



Differential Reflectivity



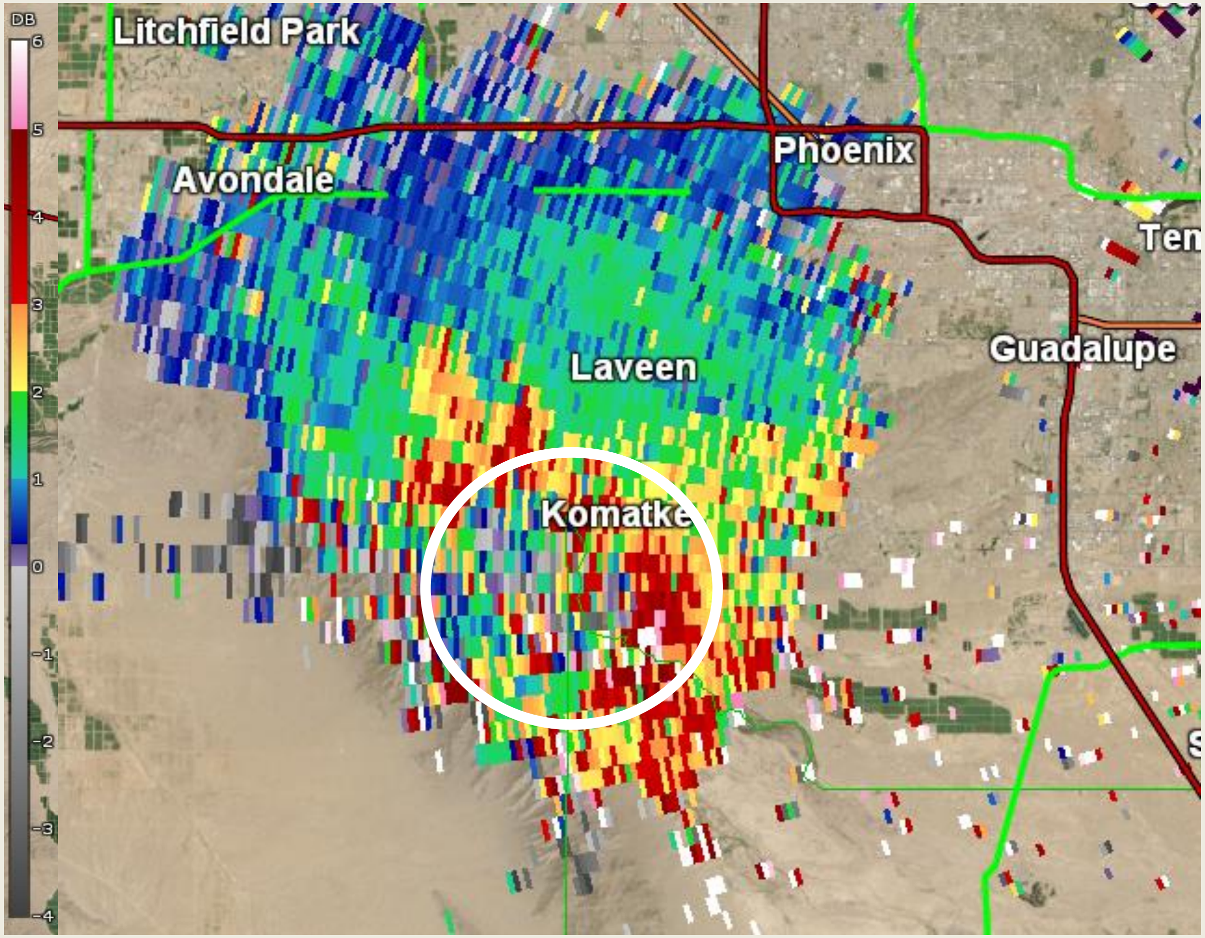
Correlation Coefficient



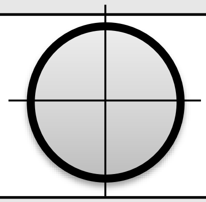
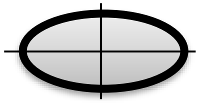
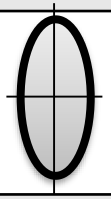
Specific Differential Phase

Differential Reflectivity: What Shape

- Compares horizontal energy return to the vertical energy return
- High values are probably big (flat) raindrops
- Low values are either small raindrops or hail



Differential Reflectivity: What Shape

Spherical	Horizontally Oriented	Vertically Oriented
X = Y	X > Y	Y > X
		
Z_{DR} ~ 0 dB	Z_{DR} > 0 dB	Z_{DR} < 0 dB

NWS State College

Units: dB

A measure of the mean shape of particles in the sampling volume.

Differential Reflectivity: What Shape

Spherical particles

Z_{DR} = 0 dB

Small, non-spherical particles

Those with their major axis aligned in the **horizontal:**

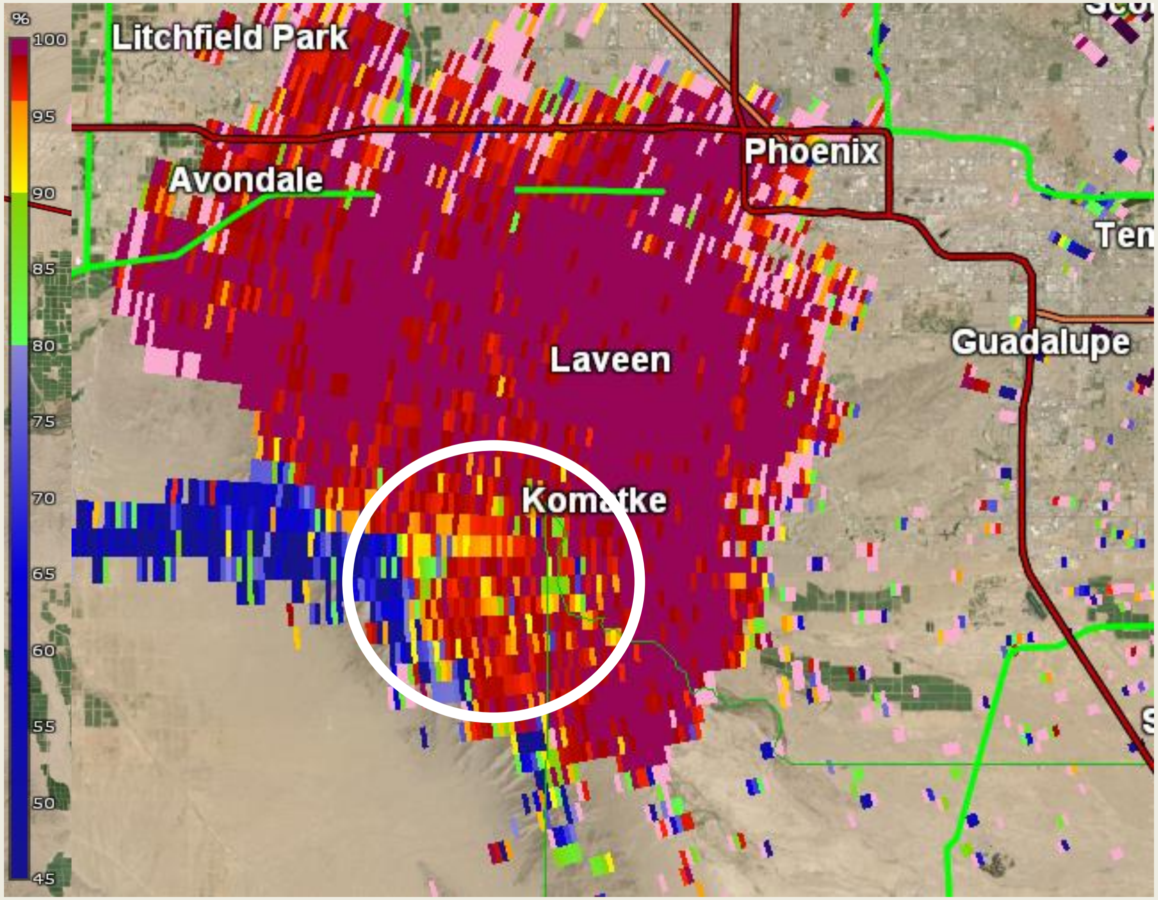
Z_{DR} > 0 dB

Those with their major axis aligned in the **vertical:**

Z_{DR} < 0 dB

Correlation Coefficient: How Similar

- Measures how similar precip. particles are
- High values = same type/size of particles
- Lower values = mixed rain/hail, non-weather targets



Correlation Coefficient: How Similar

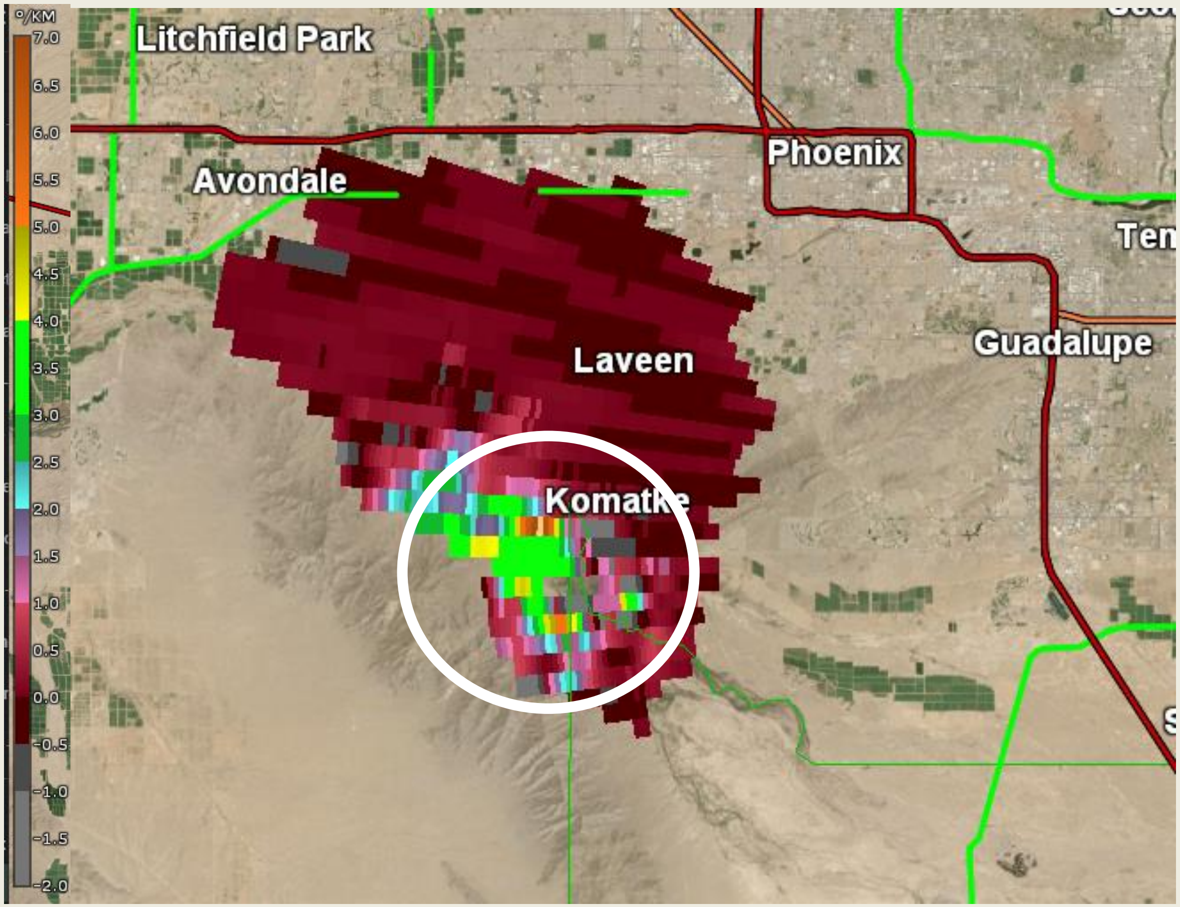
Meteorological (Uniform)	Meteorological (Non-Uniform)	Non-Meteorological
Rain, Snow, etc	Hail, Wet Aggregates (melting snow)	Birds, insects, debris
High CC (>0.97)	Moderate CC (0.80 to 0.97)	Low CC (<0.8)

NWS State College

Units: None

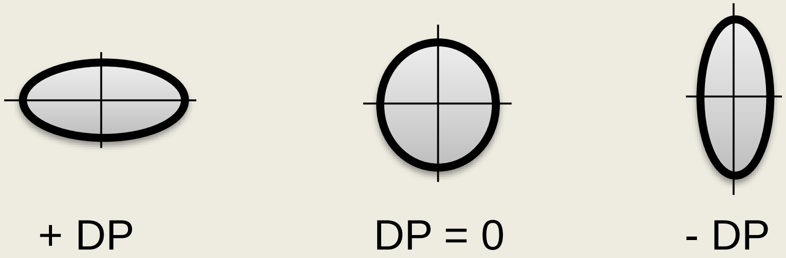
Specific Differential Phase: How Many

- Measures how the beam changes as it passes through precip.
- Big change = lots of raindrops
- Small change = fewer drops (maybe hail)
- Important for precip. estimates

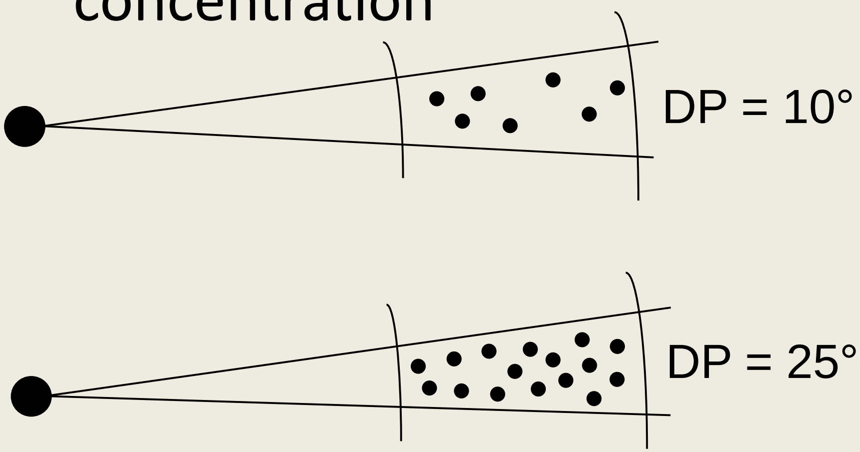


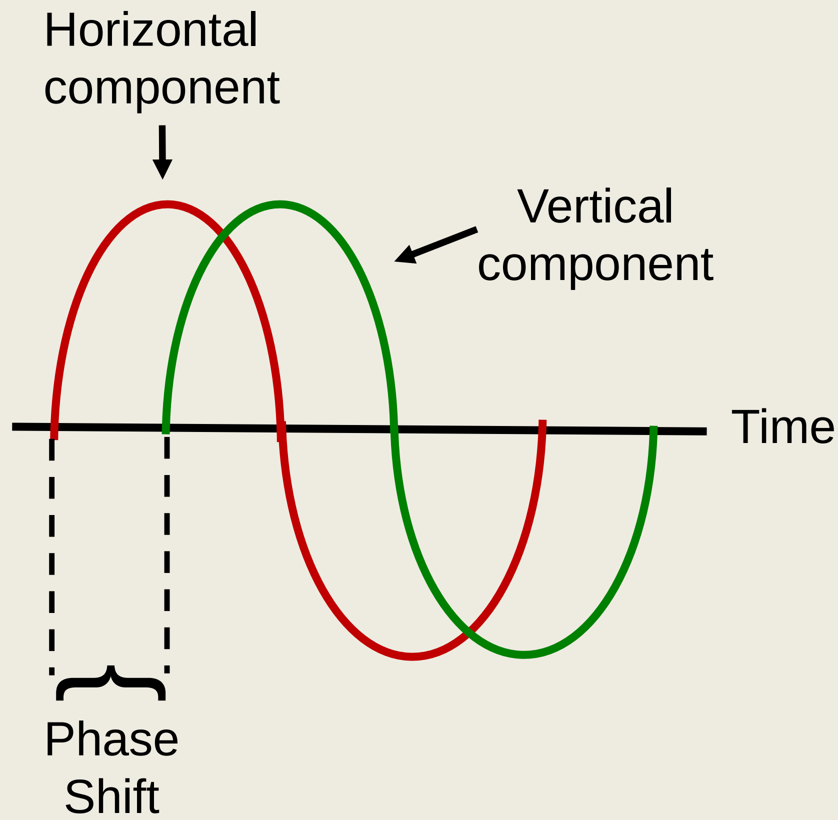
Specific Differential Phase: Phase Shift

- Dependent on shape (like ZDR)



- Also affected by particle concentration





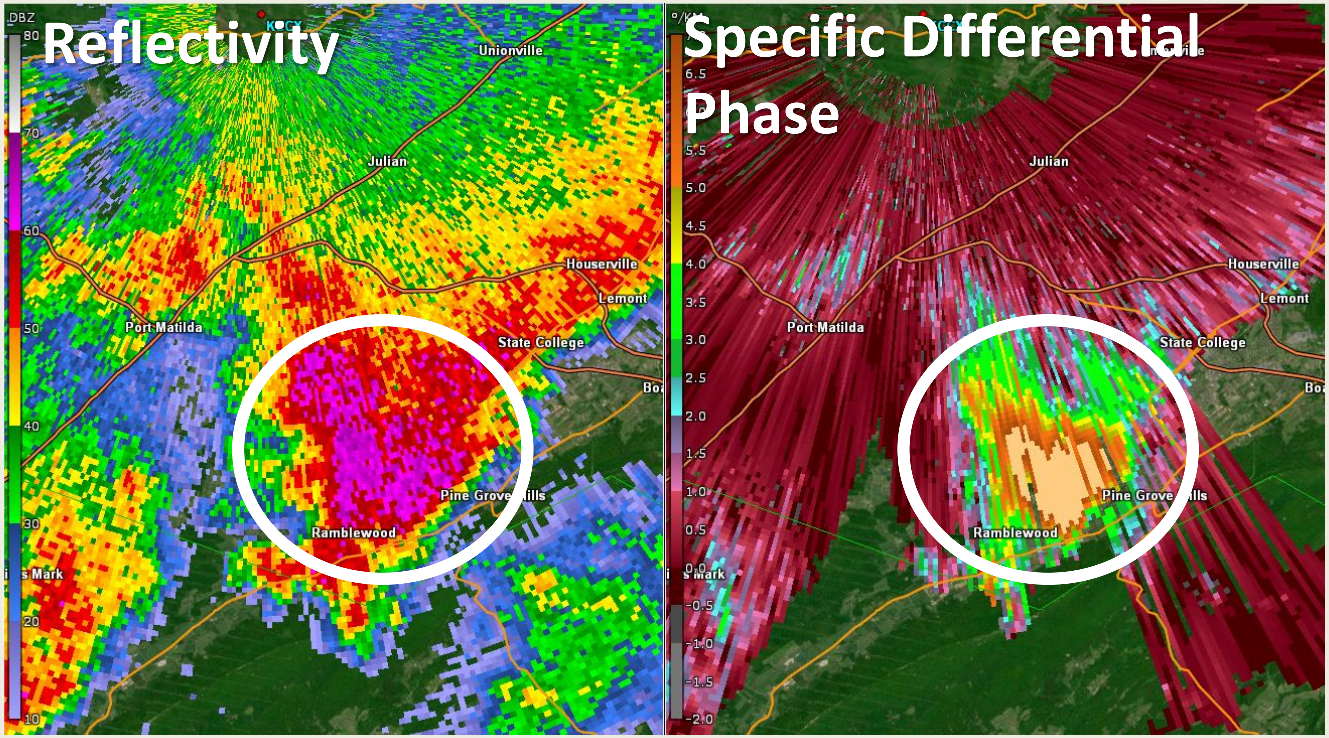
Specific Differential Phase: Application

Large values of specific differential phase collocated with large values of reflectivity may indicate

very heavy rain

or

large amounts of small melting hail



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- Case Studies

Case Study #1

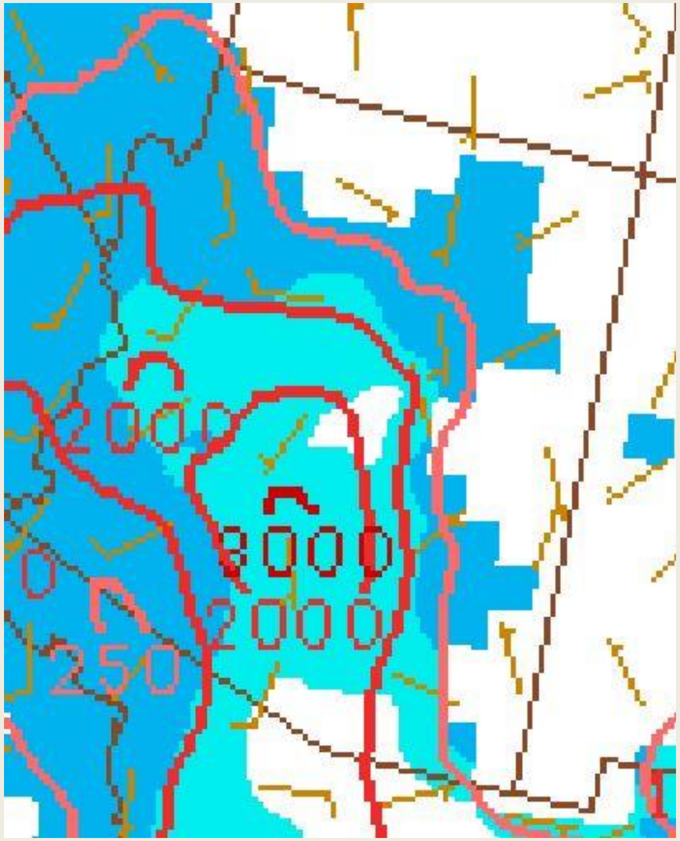
- Moisture/Instability
  - Large CAPE (2000-3000 J/kg MLCAPE)
  - Moderate CIN (25-100 J/kg MLCIN)
  - Moderate to Large DCAPE (1000-1500 J/kg)
  - Low to Moderate LCL Heights (1000-2000 m)

- Environmental Winds/Shear
  - Weak deep shear (<25 kts Effective Shear)
  - Weak low level shear (less than 10 kts of 0-1 km shear)
  - Weak steering flow (5-10 kts 850mb-300mb)

Thermodynamics

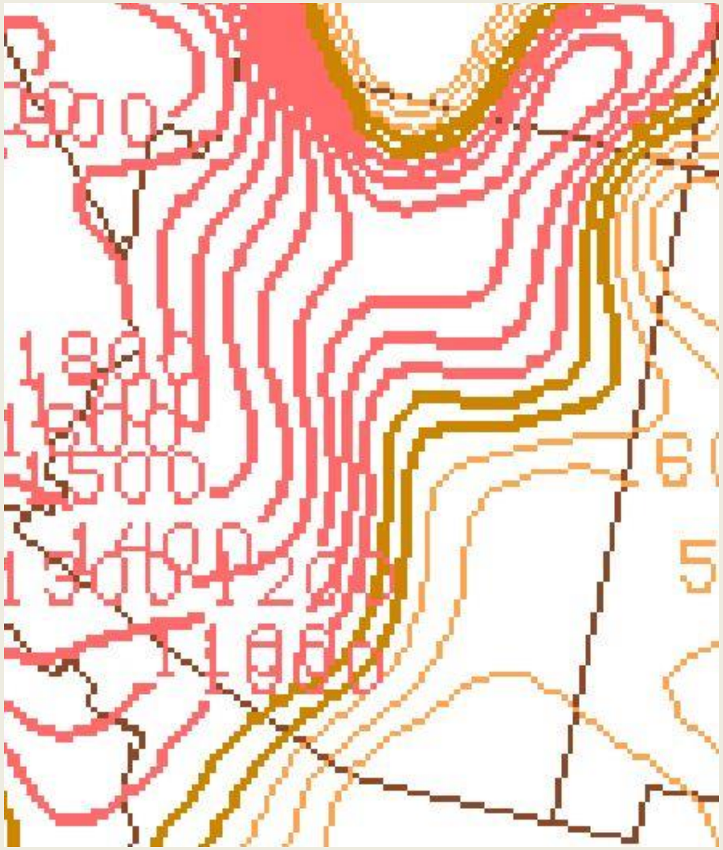
MLCAPE

10pm



DCAPE

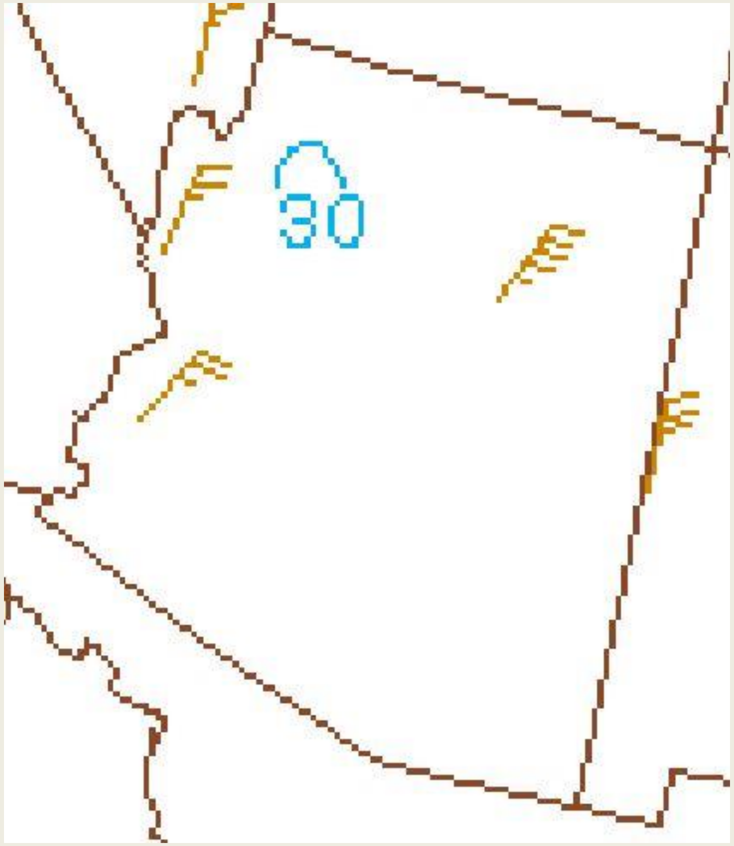
10pm



Kinematics

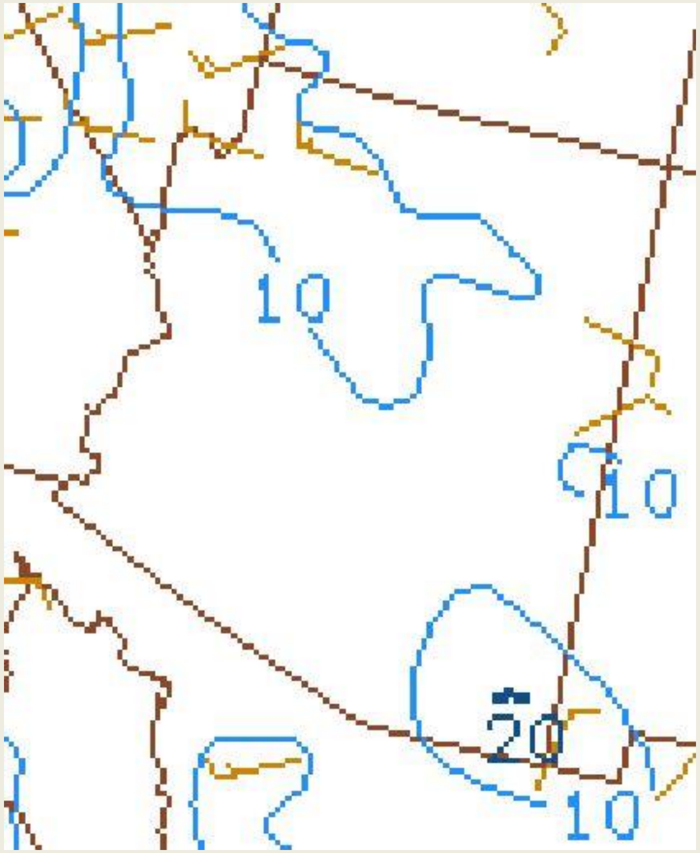
Effective Shear

10pm



0-1km Shear

10pm

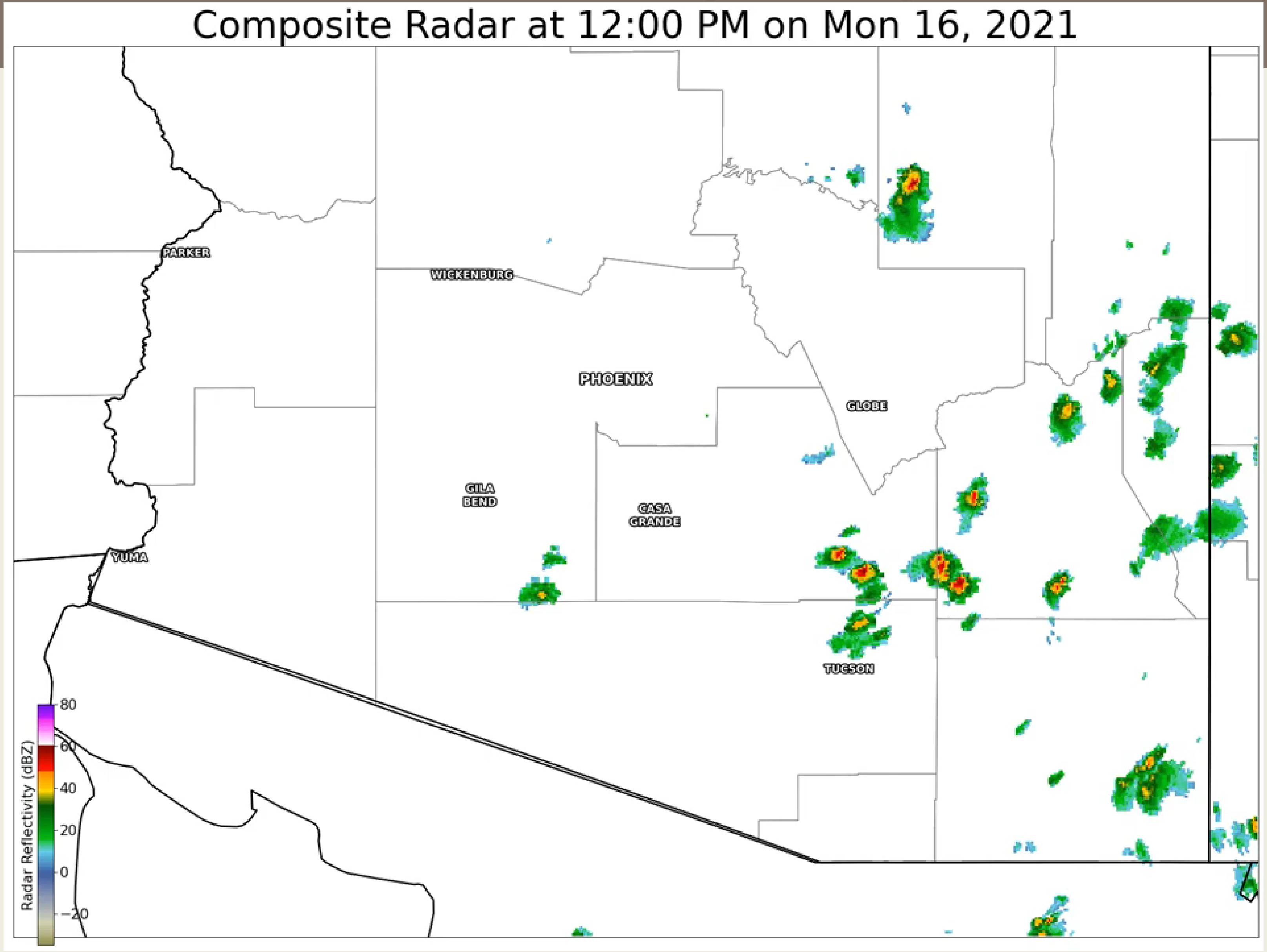


Kinematics

850mb - 300mb Average Winds

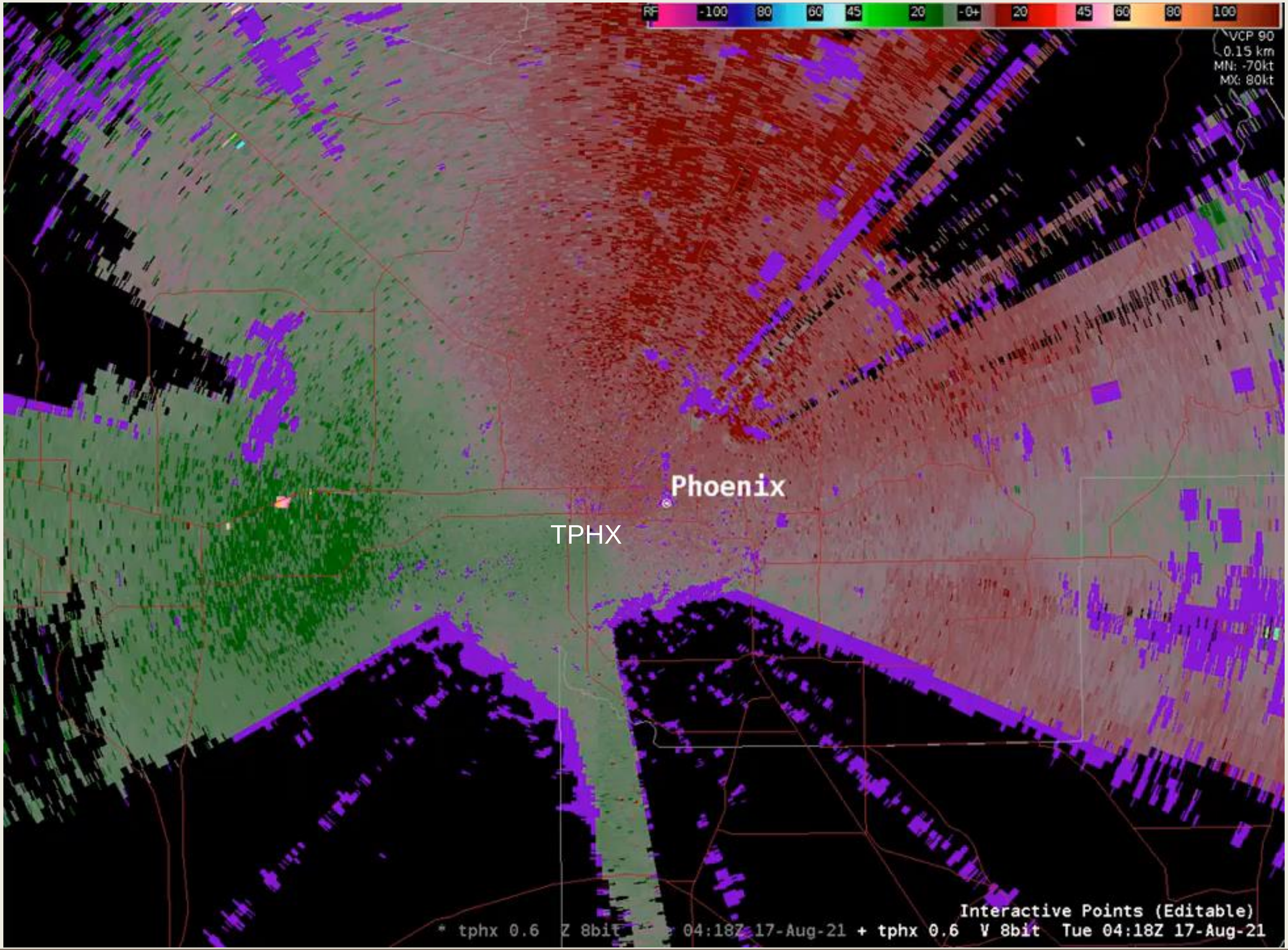
10pm

Reflectivity Loop



Base Velocity Loop

9:19 PM – 12:59 AM




Phoenix
Kim Quintero – AZ Family


Laveen
@reinazee

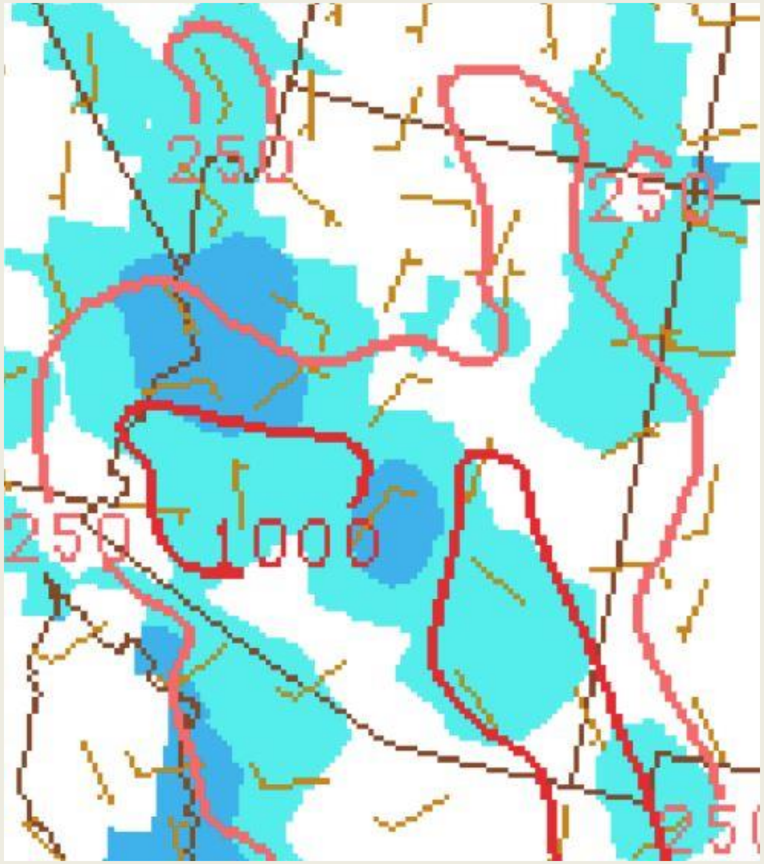
Case Study #2

- Moisture/Instability
  - Moderate CAPE (~1000 J/kg MLCAPE)
  - Moderate CIN (25-100 J/kg MLCIN)
  - Moderate to Large DCAPE (1000-1200 J/kg)
  - Moderate LCL Heights (1000-1500 m)
- Environmental Winds/Shear
  - Strong deep layer shear (40-50 kts Effective Shear)
  - Weak to moderate low level shear (~10 kts of 0-1 km shear)
  - Moderate to strong steering flow (30 kts 850mb-300mb average wind speed)

Thermodynamics

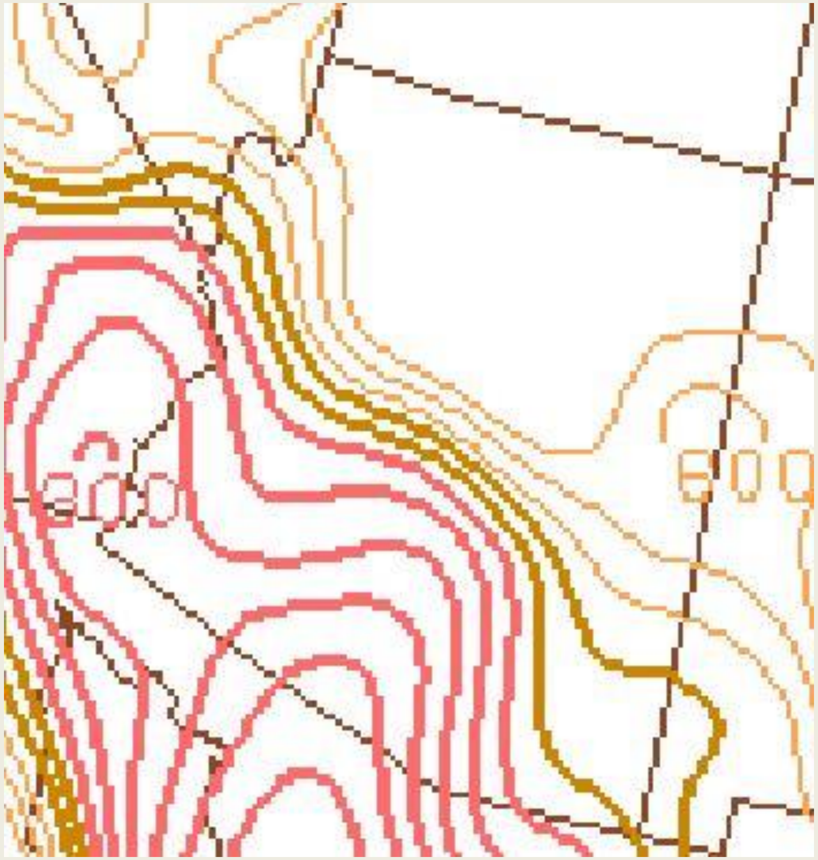
MLCAPE

4pm



DCAPE

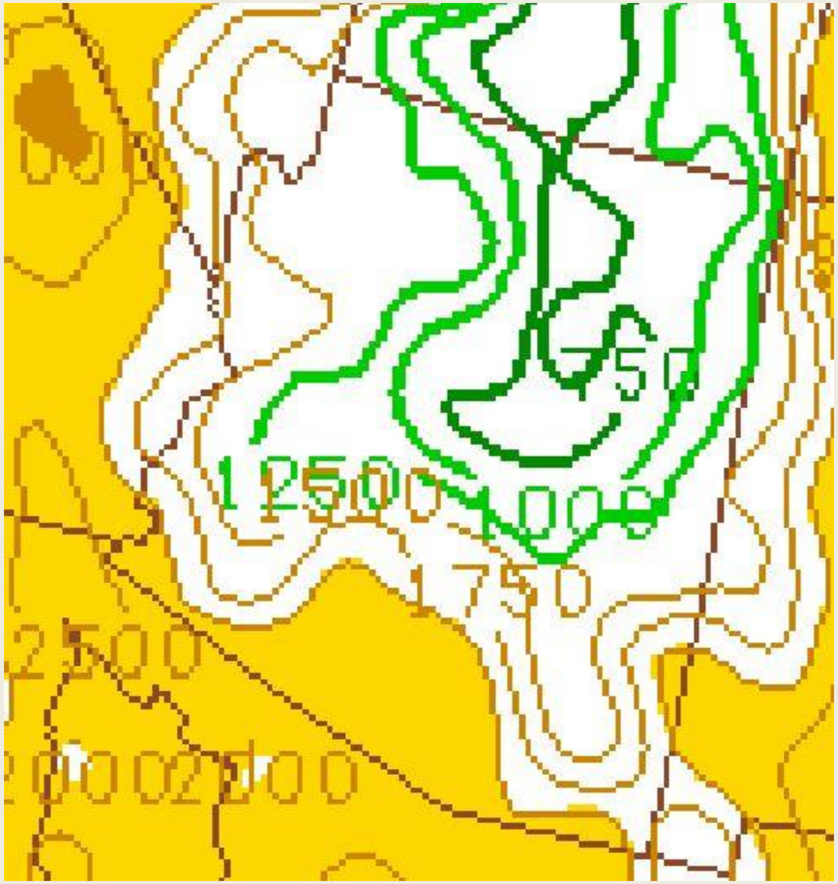
4pm



Thermodynamics

LCL Height

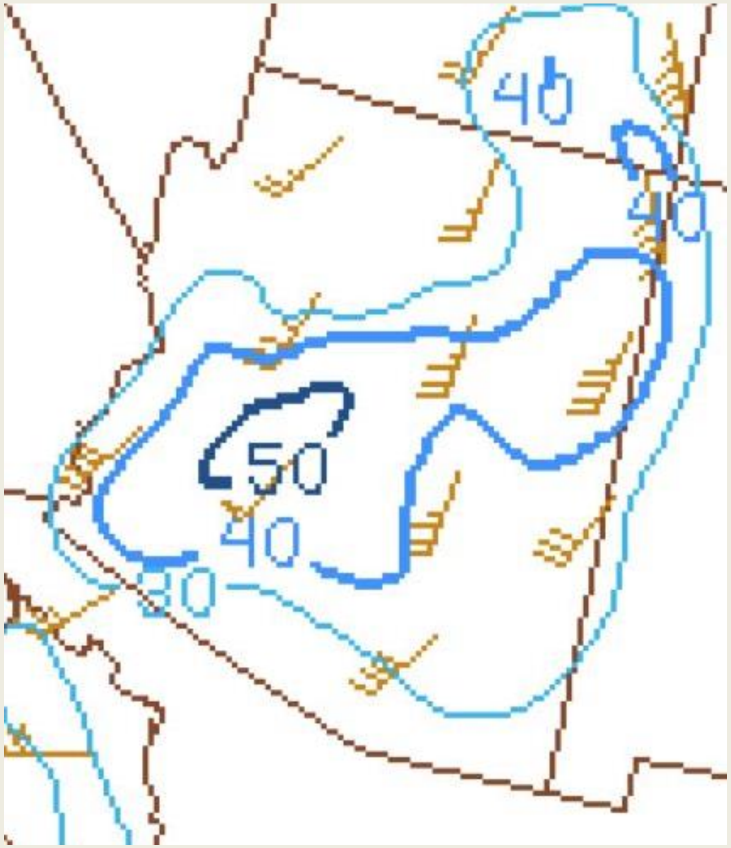
4pm



Kinematics

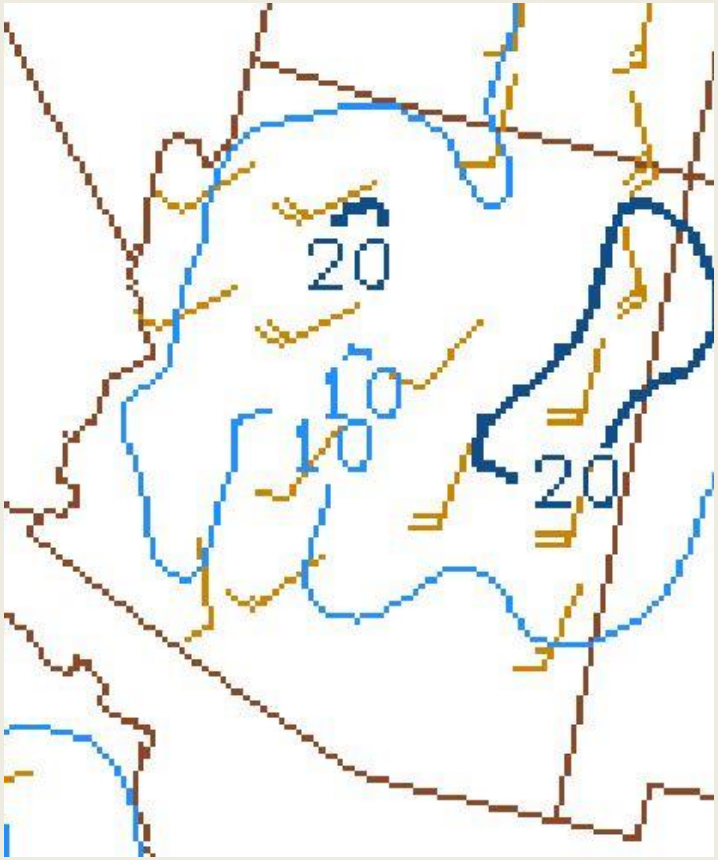
Effective Shear

4pm



0-1km Shear

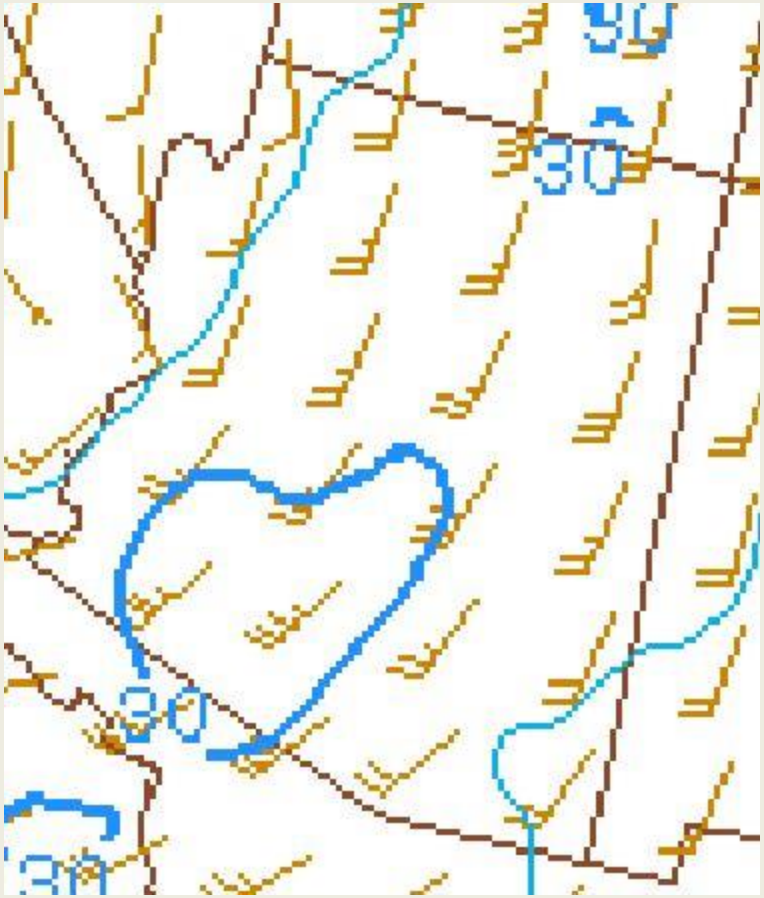
4pm



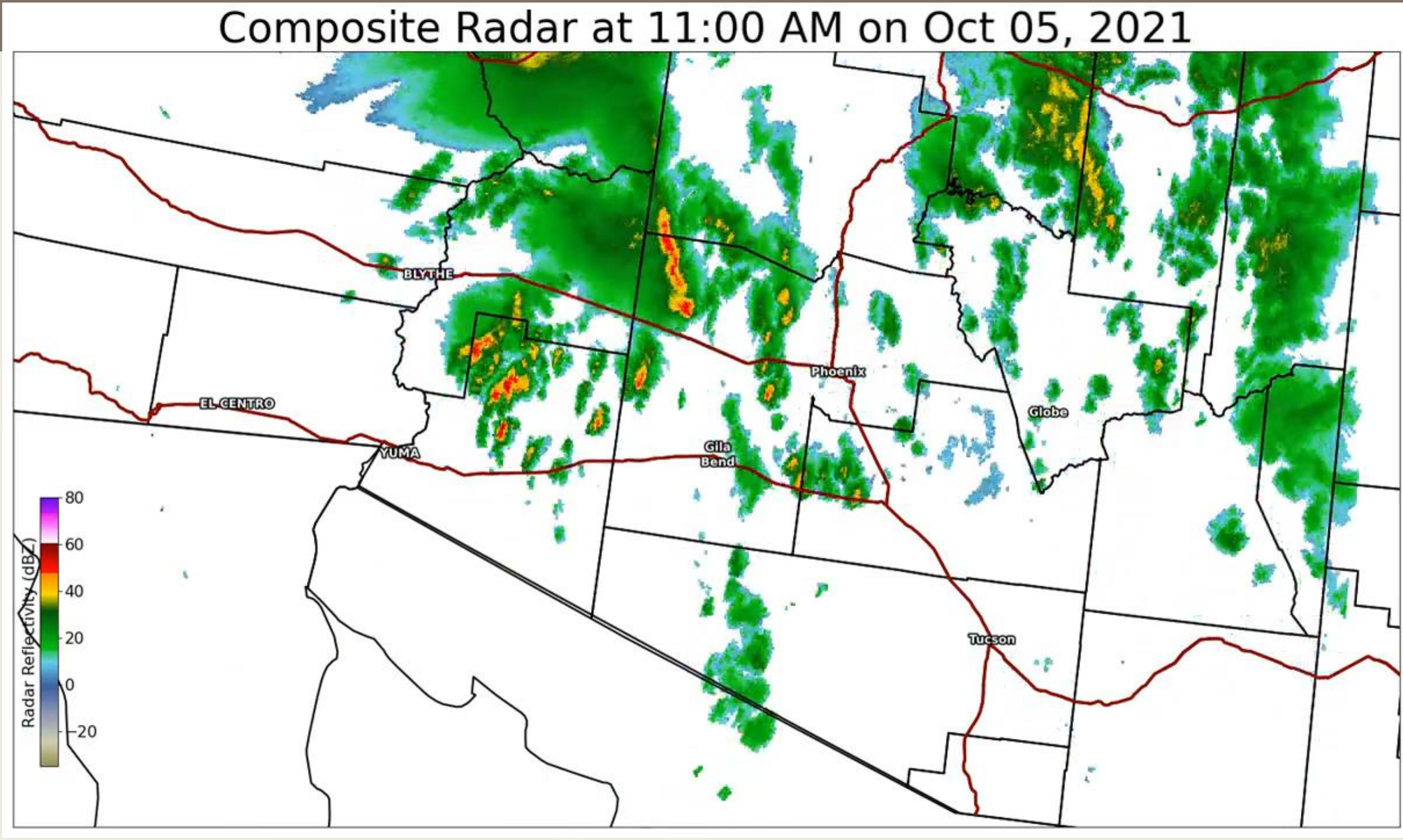
Kinematics

850mb - 300mb Average Winds

4pm



Reflectivity Loop



Base Reflectivity Loop

2:06 PM – 6:36 PM

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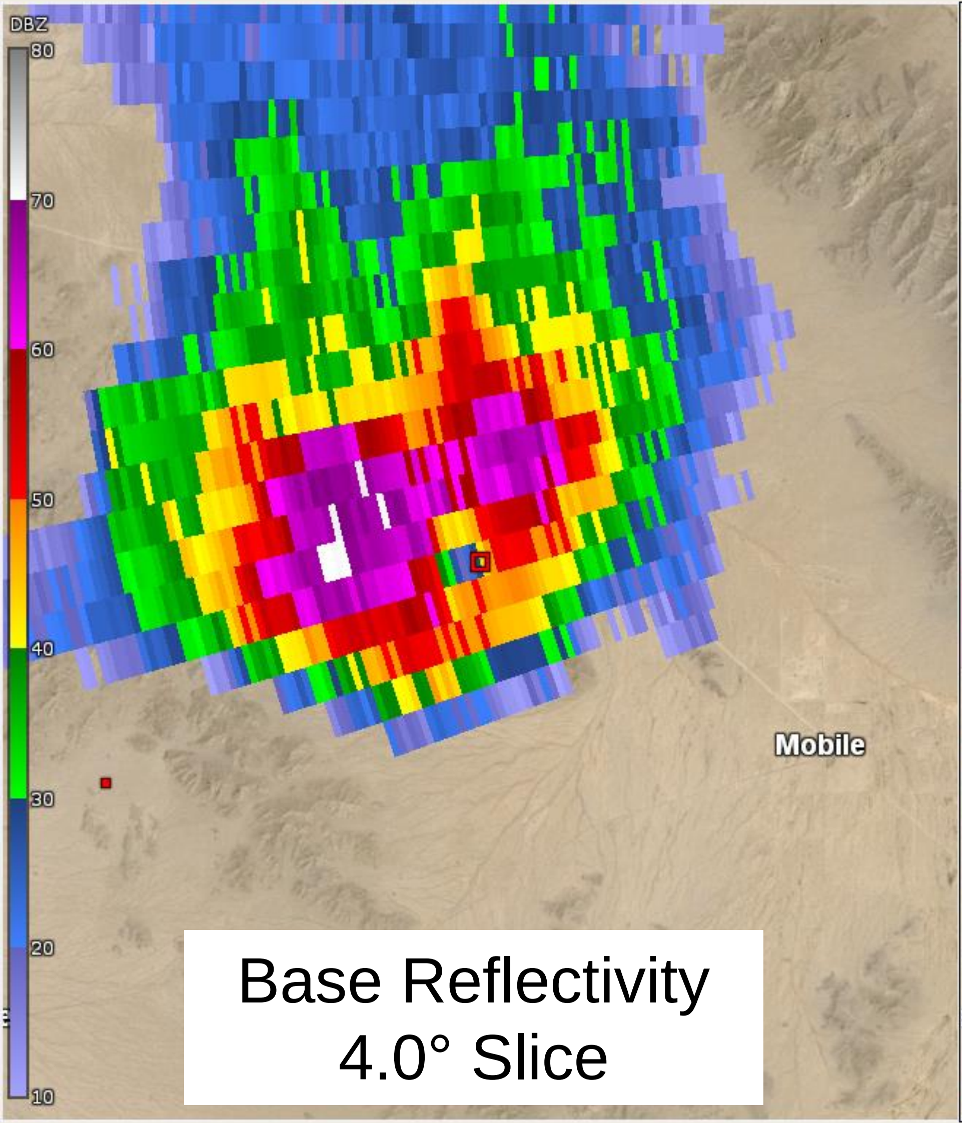
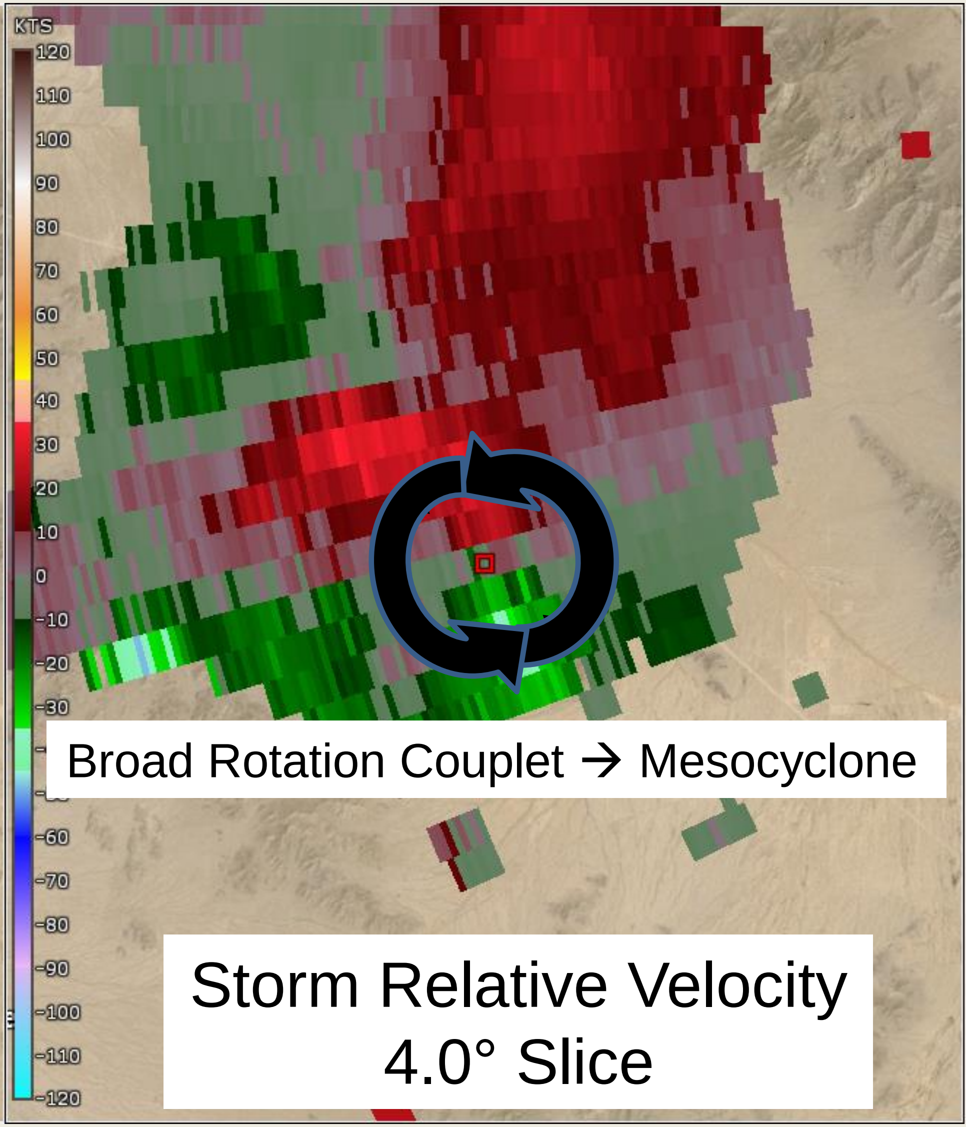
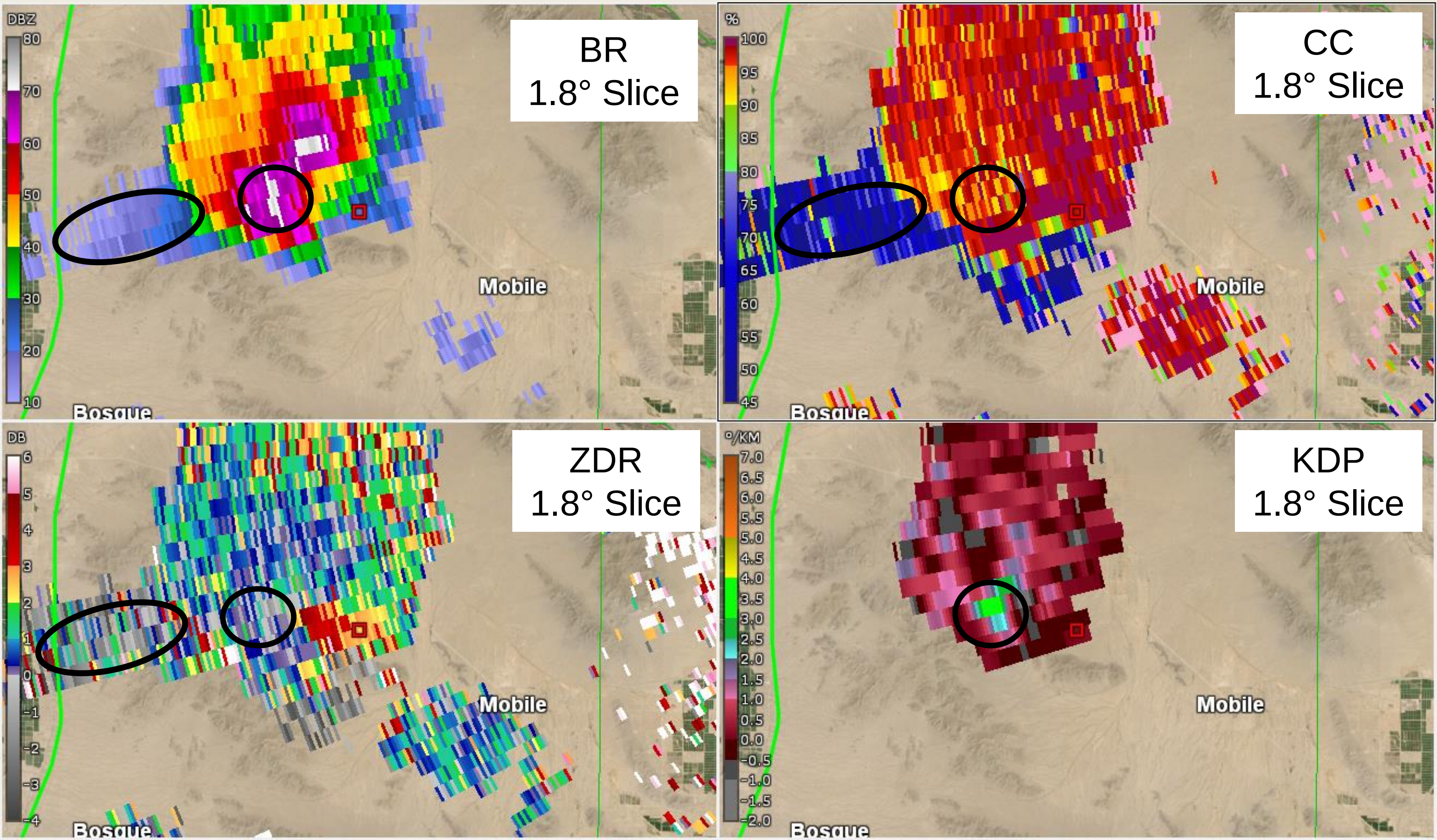
5pm


DBZ
80
70
60
50
40
30
20
10
Mobile
Base Reflectivity
4.0° Slice

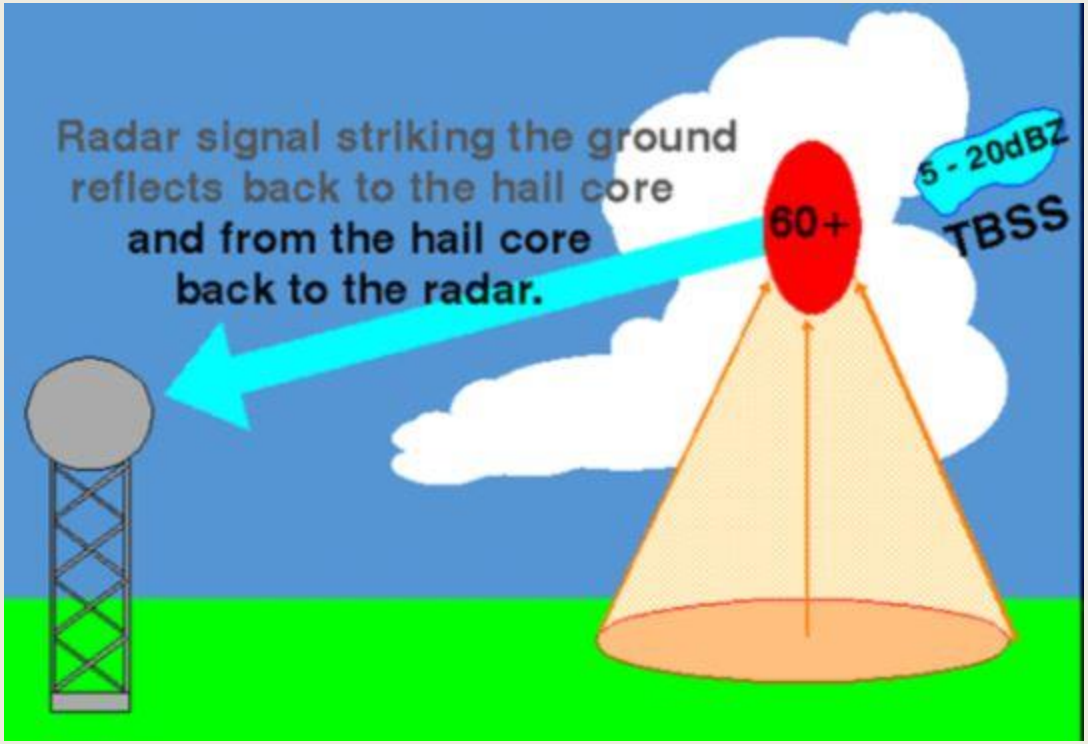

KTS
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-60
-70
-80
-90
-100
-110
-120
Broad Rotation Couplet → Mesocyclone
Storm Relative Velocity
4.0° Slice

Dual Pol Data

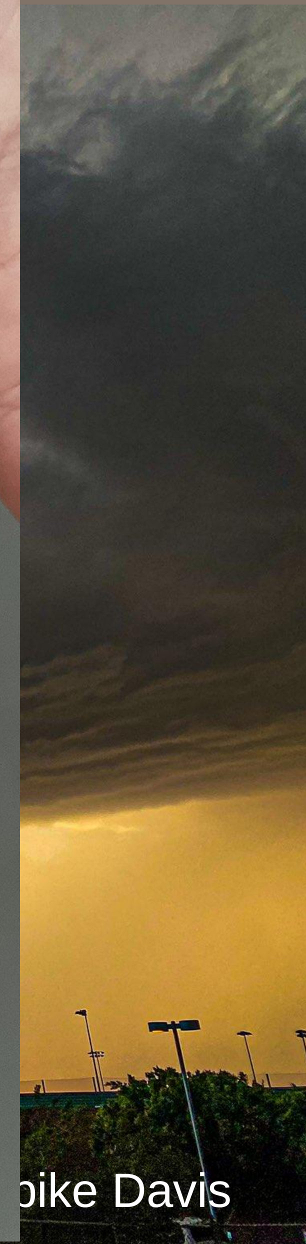
5PM



Three Body Scatter Spike (Hail Spike)



NWS WDTD



/

ov/psr

Course Summary

- A delicate balance of environmental ingredients is needed for severe storms
- Understanding these environmental conditions can assist spotter operations
- Anticipation of storm behavior will help with your situational awareness
- Knowledgeable spotters combined with skilled forecasters and proactive EM and media results in the best warning system
- ALWAYS THINK SAFETY FIRST!

Questions? Contact Us!

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602-275-7418 (Public Line)

Photo: Dennis Griffin